

# Seasonal March of Climatic Conditions in a Greenhouse, as related to Plant Growth

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By  
EARL S. JOHNSTON

*Diss.*

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## THE SEASONAL MARCH OF THE CLIMATIC CONDITIONS OF A GREENHOUSE, AS RELATED TO PLANT GROWTH<sup>1</sup>

EARL S. JOHNSTON.

### ABSTRACT

The study here reported was undertaken to measure and integrate the climatic conditions of a greenhouse by means of various measurements taken from standard plants, as these conditions varied throughout the year, and also to measure and integrate these same environmental conditions in terms of instrumental data, to prepare for an analysis of such an environmental complex and an interpretation of the plant values by means of the instrumental ones.

The general method employed by McLean was followed. Buckwheat plants (approximately alike at the start, when they were small seedlings) were grown for 4-week exposure periods during a total time period of thirteen months. A new period began every fortnight. The plants were grown in solution culture and the chemical surroundings of the roots were practically the same in all cases. Such culture plants are considered as integrating instruments for measuring the climatic conditions, as these effect plant processes. Measurements of stem height, dry weight, leaf area and transpiration were made at regular intervals as "readings" of these "instruments". Simultaneous measurements of evaporation, radiation and temperature were also obtained. These plant and instrumental measurements were made from two series of tests, one conducted under the ordinary conditions of an unshaded greenhouse at Baltimore, the other within a cheese-cloth enclosure in the same greenhouse. Most of the measurements were recorded every week and weekly data are presented, but this paper deals mostly with the 4-week data, and mainly with the exposed series.

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1.—Botanical Contribution from the Johns Hopkins University No. 59. A dissertation submitted to the Board of University Studies of the Johns Hopkins University in conformity with the requirements for the degree of Doctor of Philosophy, June, 1917.

Delay in publication has been brought about by the unsettled conditions existing during and immediately following the war.

The seasonal march of the 4-week plant growth rates may be summarily described as follows: The rates for stem elongation, for dry weight increase and for leaf-area increase had high summer values and low winter ones. These values increased during the spring and decreased during the autumn. The rates of transpirational water loss varied throughout the year in a similar manner, but they showed low values about the summer solstice. The rates of stem elongation also showed remarkably low values for a period about the time of the summer solstice. The approximate annual ranges (ratios of maximum to minimum) were as follows: Rate of stem elongation, 2; rate of dry-weight increase, 8; rate of leaf-area increase, 5; rate of transpirational water loss, 9.

Four derived plant values are considered: (1) those obtained by averaging the 4-week rates of increase in dry weight and in leaf area, (2) the 4-week rates of transpirational water loss per unit of total dry weight (3) the 4-week rates of transpirational water loss per unit of leaf area, and (4) the 4-week rates of dry weight increase per unit of leaf area. The first of these derived values (which does not differ fundamentally from either of the two values that were averaged) gives what may be called the weight-area index of plant growth. Its maximum is 7 times as great as its minimum. The 4-week rates of transpirational water loss per unit of total dry weight (water requirement) seem to bear no general relation to the march of the season. The transpiration rates per unit of leaf area (areal coefficient of transpiration), though resembling those of the water requirement in some respects, show an indication of a seasonal march with low mid-summer values. The 4-week rates of dry weight increase per unit of leaf area (areal coefficient of dry-weight increase) exhibit a general similarity to those of transpiration per unit of leaf area, but show more clearly a seasonal march with high summer and low winter values.

The greenhouse climate during the year of this study, as measured by the plant processes mentioned above, appears to have been most favorable to the general growth of these plants during two separate periods, one in early summer (April 10 to May 22) and one in late summer (July 3 to Sept. 11). The most favorable periods for stem elongation occurred for the two 4-week periods ending May 22 and September 25. The period extending from May 22 to July 31 was very favorable for dry-weight production and increase in leaf area. It is also clear that the climatic efficiency for producing growth was lowest during the winter period (about Nov. 20 to about Feb. 26). Even with the usual application of artificial heat, the winter efficiency for plant growth remained very low.

The evaporating power of the air, as measured by the white spherical porous-cup atmometer, showed somewhat higher and more uni-



form values for the winter than for the summer. The most pronounced seasonal fluctuation was shown by indices of total radiation obtained with the radio-atmometer. There is fairly good agreement between these radiation values and those of actual sunshine duration, for corresponding periods. Maximal summer values occurred at approximately the same time for both indices, but the minimum radio-atmometric value occurred several weeks earlier than did the minimum duration value. The temperature values (average daily mean and average daily range for each 4-week period) showed a rather decided seasonal variation, with high summer values and low winter ones.

The climatic efficiency values within the cheese-cloth chamber in the greenhouse appear, in general, to have been lower than those in the unshaded greenhouse, the exceptions being the values for stem height and for leaf area, for periods about June 21. The evaporation and radiation indices for the sheltered series are much lower than those for the exposed series. Very little difference is to be noted between the corresponding temperature values for the cheese-cloth chamber and for the unshaded greenhouse.

While the interpretation of the plant values in terms of those derived from the instruments offers many difficulties, nevertheless the following striking features of this environmental complex that are registered in the records of both plants and instruments, may be mentioned:—(1) Fairly good agreement exists between the daily mean temperatures and the transpiration rates, while none of the other plant values shows such agreement with the mean temperatures. (2) The summer values for average daily temperature range and those for transpiration vary in the same direction. (3) Along with high evaporation rates in late summer occur high temperature, radiation and transpiration values, but low values for the rates of increase in dry weight and in leaf area. (4) A rather general agreement is to be observed between the radiation values and the areal coefficients of weight increase and of transpiration, but there is no very marked agreement between the radiation values and those of the water requirement. (5) With the exception of the water requirement of the plants and the evaporating power of the air, the values here studied (both plant and instrumental) exhibit low magnitudes for the winter period.

Where stem elongation is used as a criterion of growth, measurements taken after an exposure period of two weeks appear to be as satisfactory as those taken after a period twice as long. It appears that the climatic conditions effective during the first two weeks of these tests predetermined, in a great measure, the rates of stem elongation for the succeeding 2-week period in each case, so that the climatic fluctuations of the second 2-week period were practically ineffective to produce differences. These buckwheat plants appear to

have been generally much more sensitive to climatic influence during the first two weeks than during the second.

For the rate of stem elongation, and possibly also for that of transpiration, it appears that a period of low values occurs about the summer solstice.

## INTRODUCTION

Seasonal variations in greenhouses are of considerable importance to all who grow plants under glass, and a better knowledge of these variations and of the way they influence plant growth is especially needed for the interpretation of many experimental investigations in plant physiology. In most physiological investigations two sets of conditions may be considered, those that are artificially controlled and those over which no control is exercised. Since the controlled external conditions may be regarded as the same for several experiments conducted in the same way at different times, disagreements in the results obtained may be related either to the uncontrolled conditions in the plants themselves (internal conditions) or to those of the environment that are allowed to vary with the season. Care is usually taken to select plants that are at least apparently similar for the different experiments in a series of repetitions, and many such experiments employ seeds that may be regarded as practically alike for tests performed at different times of year. In spite of this, discordant results are frequently obtained and it is often supposed that these are due to differences in the uncontrolled conditions of the greenhouse, as these alter with the weather outside and with the season.

In the experimental work dealt with in this paper a single experiment on the growth of buckwheat plants in solution cultures in a greenhouse was carried out 27 times, so that the series of tests embraced the entire year, and the climatic variations occurring in the greenhouse during this long period were studied and compared by means of measurements derived from the plants themselves as well as those obtained from climatological instruments.

It was planned, in the first place, to measure and integrate the climatic conditions of a greenhouse for 4-week periods beginning every 2 weeks throughout the year, by employing standard plants for automatically obtaining environmental efficiency values such as those suggested by Livingston and McLean<sup>2</sup> and by McLean<sup>3</sup>. The general procedure for this problem is outlined in McLean's discussion. The standard plants were very young buckwheat seedlings and their environments were kept always very nearly the same with the exception of the climatic conditions, which were allowed to vary as they would

2—Livingston, B. E. and McLean, F. T. A living climatological instrument. *Science* 43: 362-363. 1916.

3—McLean, Forman T. A preliminary study of climatic conditions in Maryland, as related to plant growth. *Physiol. Res.* 2: 129-208. 1917.



in the greenhouse, during the 4-week periods. The plants were grown in solution cultures, always with the same solution. Measurements made upon the plants and data derived therefrom are regarded as direct measures of the capacity of the climatic environment to forward the growth of these plants when supplied with the solution used. The study thus deals primarily with environmental complexes expressed in terms of their efficiencies to produce growth as measured by several criteria.

The analyses of these environmental complexes into their component conditions, and some of the suggested physiological problems concerning the detailed relations existing between the various intensities of the component conditions, on the one hand, and the various plant processes, on the other, are also considered to some extent in this paper.

It is a pleasure to acknowledge indebtedness to Professor Burton E. Livingston whose supervision, criticisms and suggestions were of foremost importance in the successful completion of this study. Thanks are due to Doctor Howard E. Pulling for many helpful suggestions.

## EXPERIMENTATION AND NUMERICAL DATA

### PROCEDURE

A set of 10 similar solution cultures was started every 2 weeks and was continued for a period of 4 weeks, so that the periods of successive sets overlapped. Each culture comprised a single plant, supported by a paraffined perforated cork stopper (1.6cm. thick) with a little cotton about the stem (in the manner commonly employed for such solution cultures) in a pint "Mason" jar containing about 425 cc. of nutrient solution. Most of the light was excluded from the roots by wrapping the jars with opaque paper. The solution was renewed at the middle of each 4-week period. At the end of the third week distilled water was added to replace the loss due to transpiration. During the summer months, when the transpiration rates were high, still more water was added at about the middle of the fourth week. At the end of each week the plants were measured in several ways, in order to obtain growth-rate data by a number of different criteria.

The experiments were carried out in one of the experiment greenhouses of the Laboratory of Plant Physiology of the Johns Hopkins University. No artificial shade was applied to the greenhouse. Two sets of cultures (10 in each) were always carried out simultaneously, one (exposed series) under unmodified greenhouse conditions and the other (sheltered series) in a cheese-cloth chamber, 91 cm. square and

122 cm. high. The employment of rotating tables (first used by Livingston<sup>4</sup> for standardizing atmometers and later by Shive<sup>5</sup> for equalizing the aerial environment of plants) made it possible to secure similar conditions for all plants on the same table. Two such tables, 76 cm. in diameter with their centers 130 cm. apart in a north-south direction, were employed, one for each of the two series. These tables made a revolution in about two minutes and operated continuously throughout the entire period of the study (56 weeks), with a few short intermissions due to mechanical or electrical troubles and to the necessary manipulations of the cultures. Both rotating tables stood on a slate-top bench near the center of the room, the northernmost one enclosed in the cheese-cloth chamber. (See Fig. 1.) The tops of the rotating tables were 122 cm. above the floor of the greenhouse.

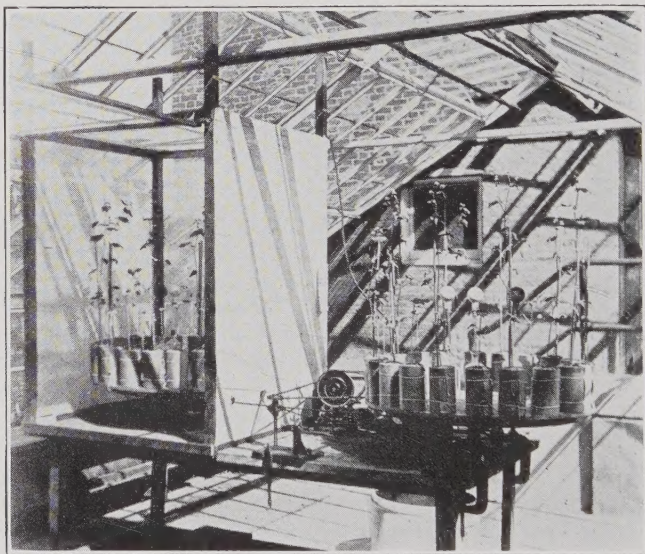


FIG. 1.—Rotating tables carrying plants and atmometers of the exposed and sheltered series. The door of the cheesecloth shelter is temporarily open for the photograph.

The nutrient solution employed was the one recommended by Shive<sup>6</sup> as producing the greatest dry weight of buckwheat tops in his study. It contained the three salts in the following volume-molecular concentrations (the total osmotic value corresponding to 1.75 atmospheres: monobasic potassium phosphate ( $\text{KH}_2\text{PO}_4$ ), 0.0144 m.; calcium nitrate ( $\text{Ca}(\text{NO}_3)_2$ ), 0.0052 m.; magnesium sulphate ( $\text{MgSO}_4$ ), 0.0200 m.<sup>7</sup> A trace of iron in the form of ferric phosphate ( $\text{FePO}_4$ )

4—Livingston, B. E. A rotating table for standardizing porous cup atmometers. *Plant World* 15: 157-162. 1912.

5—Shive, J. W. A study of physiological balance in nutrient media. *Physiol. Res.* 1: 327-397. 1916.

6—Shive, J. W. A three-salt nutrient solution for plants. *Amer. Jour. Bot.* 2: 157-160. 1915.

7—The numbers indicate the fraction of the molecular weight of the salt in a liter of solution at about 20° C.



was added. Salts of high purity were obtained at the outset, in amounts sufficiently large for the entire study. The entire supply of each salt was rendered as uniform as possible by grinding and mixing, and was then subdivided by weighing into smaller portions, each portion being sealed in a separate bottle and thus preserved until used. The portions were of such size that a single one of each salt was required whenever a fresh solution was to be prepared. Owing to the varying amounts of water in the calcium nitrate as it came from the maker the stock of this salt was first dried at 150° C. until analysis<sup>8</sup> showed that each gram-molecule contained a single molecule of water, whereupon it was subdivided and sealed in bottles as stated above.

When a quantity of nutrient solution was to be prepared a molecular solution of each salt was first made. From the proper amounts of these single-salt solutions 18 liters of the nutrient solution were prepared, sufficient for the new cultures and for the renewals. The distilled water used was obtained from a "Barnstead Automatic" water still.

Buckwheat (*Fagopyrum esculentum* Moench.) was used as the standard plant. It thrives well in water-cultures and its general habit of growth, together with the short-time required for the production of flowers and seeds (from 4 to 6 weeks in these experiments), make it a very satisfactory plant for such studies as the present one. The seed was obtained from the Bureau of Plant Industry of the U. S. Department of Agriculture, and the seed-label bore the legend "Sando Soba, C. I. no. 8, grown at Ames, Iowa, 1914." The main supply was stored in closed paraffined-paper containers (such as were employed by McLean for the same purpose) in a basement room.

About 500 seeds were germinated at a time, on moist filter paper in a suitable glass crystallizing dish covered with a glass plate. (See Fig. 2.) They were kept at room temperature until the roots had grown to a length of about 1 cm. From the seedlings thus obtained, a hundred individuals were selected for similarity of appearance and were placed, one by one, on the germination net in the greenhouse. The germination net used was similar to the one described by Shive (see Fig. 3); over a rectangular glass dish (30 cm. long, 15 cm. wide and 10 cm. deep) were stretched and fastened two pieces of paraffined cotton mosquito-netting separated from each other by a piece of bent glass tubing about 0.5 cm. thick. During the subsequent growth of the seedlings tap water was allowed to flow through the germinator. A record was kept of the daily maximum and minimum temperatures of the water.

In order that the seedlings might always be of the same approximate size when the cultures were started, three lots of seeds were placed

<sup>8</sup>—This analysis was made by Dr. F. M. Hildebrandt.

in the moist chambers on successive days and all three lots were grown on the germination net until the date selected for starting the new cultures. It was thus possible to select the 20 seedlings required for each double set so that they were always very nearly of the same size and of the same general appearance. The 20 cultures of each double set were divided into two sets of 10 each, the two being as nearly alike as possible, and each was placed on its rotating table. At the beginning of each set, and at weekly intervals thereafter, the cultures were weighed, to determine the water lost by transpiration. At the end of each week the height of each stem and the length and width of each leaf (cotyledons excepted) were recorded. A record was kept of the number of flowers and seeds produced by each plant.

After four weeks of growth in the nutrient solution each set was discontinued, as has been stated. At this time the weekly plant

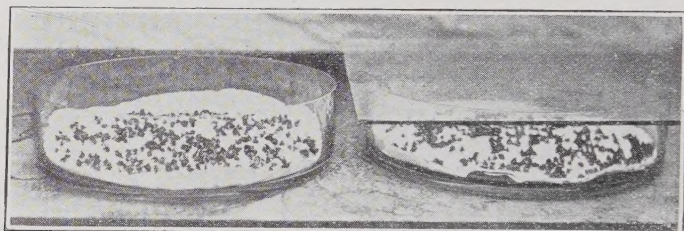


FIG. 2.—Moist chambers with germinating seeds.

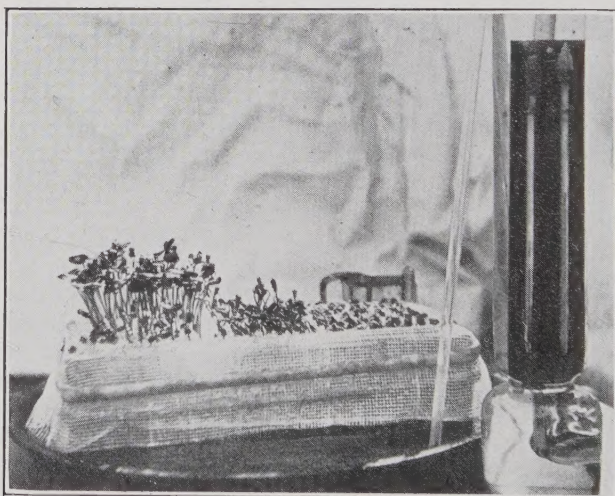


FIG. 3.—Germination net showing three consecutive sets of seedlings. The water supply passes through the glass cylinder at the right, in which are registered its daily maximum and minimum temperatures.



measurements were made for the fourth time. Notes regarding the general appearance of the plants were also recorded. The root system of each plant was separated from the stem at the region of junction of stem and root and the two portions were afterwards separately dried at 102° C., and finally weighed, to give the dry yield of tops and of roots. Before the tops were dried, and while the leaves were still fresh, photographic contact prints were made of all leaves, these prints serving for the planimetric determination of the final leaf area of each plant. These leaf areas, as recorded, represent only one leaf surface, upper or lower; of course the true total leaf area of the plant is to be obtained by doubling the value secured by the planimeter.

A continuous tracing of the air temperature in the shade, just beneath each rotating table, was obtained by means of a thermograph, the instrument being standardized every two weeks to a mercury thermometer. The evaporating power of the air was measured and recorded for each week period by means of a Livingston white spherical porous cup atmometer.<sup>9</sup> This instrument, in each case, stood on the rotating table somewhat nearer the center than did the plant cultures. To obtain weekly records of the intensity of radiation, as this might affect evaporation or transpiration, a Livingston radio-atmometer was also operated on each table. This instrument consists of two spherical porous-cup atmometers, one with a white sphere and the other with a black. Since the black spheres that were available when this work was begun were a little larger (5.15 cm. in diameter) than the standard white spheres, the white sphere of the atmometer was not employed as the white member of the radio-atmometer, but a second white sphere, corresponding in size to the black one, was employed in the double instrument. The three atmometers were equally distant from each other and from the center of the rotating table and were similarly arranged on the two tables. (See Fig. 1.) The weekly readings obtained from the standard white spheres were corrected to the Livingston spherical standard and those obtained from the two somewhat larger spheres of the radio-atmometer were corrected to a special standard for that particular size of spherical cup. Thus, the records obtained from the standard white sphere are comparable with other records from that instrument that have been or may be published, but the radio-atmometer records of this study are always slightly different from those that would have been obtained had the regular standard black sphere now on the market been available. The radiation records of this study, however, are to be regarded as very nearly proportional to, and not greatly different from, those that would have been obtained from the standard radio-atmometer.

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<sup>9</sup>—Livingston, B. E. Atmometry and the porous cup atmometer. *Plant World* 18: 21-30, 51-74, 95-111, 143-149. 1915.

## PRESENTATION OF COMPUTED DATA.

*Introductory.* The numerical data obtained from the various measurements and readings were finally computed as summations or as averages. They may be classified into two general groups, those obtained from plant measurements and those obtained from instrumental measurements. These two general groups of data are each divided into two sub-groups, one representing the exposed series and the other the sheltered one.

Since most of the measurements, both plant and instrumental, were made weekly there are in nearly every case four sets of weekly data available for each 4-week period represented, for the exposed and for the sheltered series. There is, however, but one set of data for dry weight and but one for leaf area, since measurements for these were taken only when the culture sets were discontinued at the end of the 4-week period in each case. The original measurements were taken from single plants and, as there were ten plants in a set, except where one or two were lost because of accident, the numerical plant values have been averaged, so that the plant data presented in the following tables represent measurements of a hypothetical *average* plant in each particular set.

The numerous data computed from measurements taken in this study are presented in the tables. Tables I-VIII present data derived from plant measurements and tables IX and X present those from instrumental measurements. Tables XI-XIV give summarized and derived plant and instrumental data for the 4-week culture periods. The last two tables, XV and XVI, give monthly indices.

*Plant data.* Table I gives the numbers of the culture periods (which are the numbers of individual sets) in chronological order together with their dates of beginning and ending. It also gives data on the preliminary germination period for each set and the maximum and minimum water temperature in the germinator for all but the first five periods, for which no such records were kept. Since the seedlings of corresponding sets of the exposed and sheltered series were obtained from the same germinator at the same time, this table is applicable to either series. There were no differences in the lengths of the experiment periods, these being always 4 weeks, but considerable differences occurred in the lengths of the germination periods, both in the moist chamber and on the germination net. The minimum time required to produce seedlings of proper size to be placed in the culture jars was 3.5 days (period ending July 31) and the maximum was 8 days (period ending February 26). These differences in length of germination periods were no doubt due to differences of temperature in the germinator and on the germination net.

Table II presents data showing the average number of leaves per plant for each set of the exposed and sheltered series. In the first column dates of ending of the culture periods are given. (The various cultures are designated by the dates of their endings in this and



all following tables.) The average total number of leaves for each set at the end of each week period is presented in the four double columns. Cotyledons are not recorded as leaves in this table. The total number of leaves at the end of any four-week period is of course the same number as that recorded for the end of the fourth week.

Table III shows the average number of flowers and seeds per plant for each set of the exposed and sheltered series. At no time were there flowers at the end of the second week, so that the only counts of flowers were obtained at the ends of the third and fourth weeks. The results of these counts are tabulated in the first two double columns. During some periods the flowers were so numerous that their number was simply estimated. The last double column records the number of seeds at the end of the fourth week. Only a single case occurred where the plants of the sheltered series set seed. This one case (period ending Sept. 25) occurred at the time of the maximum seed yield for the exposed series.

In table IV data showing the average height of the plants in each set of the exposed and sheltered series are given. The average initial height for each set at the time the seedlings were placed in the culture jars is recorded in the first double column. The other four double columns record the heights at the end of each of the four weeks. The height here considered was taken as the distance from the upper surface of the cork in the culture jar to the base of the terminal bud on the main stem. The actual average heights of the plants may be approximately obtained by adding the thickness of the cork (1.6 cm.) to each of the heights given in the table. The gain in average height after one, two, three or four weeks of growth may be obtained by subtracting the initial average height from the proper weekly average in each case.

Table V notes the average number of branches, average total length of branches and average total cylindrical portion formed per plant, for each set of the exposed and sheltered series (excepting for the first two sets, for which these measurements were not made). By total cylindrical portion is meant the sum of the height and the lengths of all the branches; this is given only for the end of the 4-week period.

In table VI is seen the average total transpiration per plant for each set of the exposed and sheltered series, as if measured at the end of each week. The loss for any single week may be obtained by subtracting from the total for the period ending with that week the total for the preceding period.

Table VII presents data showing the average dry weights of top, roots and entire plant, and the average total leaf area and cotyledon area per plant for each set of the two series, as obtained for the end of the 4-week period. The initial average dry weight (for the

beginning of each experiment, when the seedlings were placed in the culture jars) was about 0.013 grams. This value was obtained by averaging the dry weights of 20 seedlings such as those placed in the culture jars at the beginning of each set. The grain in average dry weight for any 4-week culture period may be approximately obtained by subtracting the initial average from the final dry weight average as given in the table. The values for total leaf area appearing in the fourth double column of this table represent in each case, the sum

TABLE I.

*Dates of beginning and ending of each set and lengths of germination periods, with maximum and minimum water temperatures in germinator*

| Set No. | Period    |          | Length of germination period <sup>a</sup> |                    |       | Water temperature in germinator <sup>b</sup> |         |
|---------|-----------|----------|-------------------------------------------|--------------------|-------|----------------------------------------------|---------|
|         |           |          | in moist chamber                          | on germination net | total | Maximum                                      | Minimum |
|         | Beginning | Ending   |                                           |                    |       | Deg. C.                                      | Deg. C. |
|         | 1916      | 1916     | Hours                                     | Days               | Days  |                                              |         |
| 1       | Feb. 14   | Mar. 13  | 50                                        | 5                  | 7.0   | ..                                           | ..      |
| 2       | 28        | 27       | 48                                        | 4                  | 6.0   | ..                                           | ..      |
| 3       | Mar. 13   | Apr. 10  | 47                                        | 5                  | 7.0   | ..                                           | ..      |
| 4       | 27        | 24       | 48                                        | 4                  | 6.0   | ..                                           | ..      |
| 5       | April 10  | May 8    | 48                                        | 4                  | 6.0   | ..                                           | ..      |
| 6       | 24        | 22       | 32                                        | 4                  | 5.5   | 27                                           | 15      |
| 7       | May 8     | June 5   | 49                                        | 3                  | 5.0   | 25                                           | 16      |
| 8       | 22        | 19       | 40                                        | 4                  | 5.5   | 30                                           | 11      |
| 9       | June 5    | July 3   | 55                                        | 3                  | 5.5   | 30                                           | 17      |
| 10      | 19        | 17       | 44                                        | 3                  | 5.0   | 24                                           | 19      |
| 11      | July 3    | 31       | 37                                        | 2                  | 3.5   | 29                                           | 21      |
| 12      | 17        | Aug. 14  | 49                                        | 2                  | 4.0   | 27                                           | 23      |
| 13      | 31        | 28       | 30                                        | 3                  | 4.5   | 32                                           | 21      |
| 14      | Aug. 14   | Sept. 11 | 33                                        | 3                  | 4.5   | 31                                           | 20      |
| 15      | 28        | 25       | 45                                        | 2                  | 4.0   | 36                                           | 21      |
| 16      | Sept. 11  | Oct. 9   | 33                                        | 3                  | 4.5   | 27                                           | 19      |
| 17      | 25        | 23       | 48                                        | 3                  | 5.0   | 25                                           | 17      |
| 18      | Oct. 9    | Nov. 6   | 69                                        | 2                  | 5.0   | 27                                           | 18      |
| 19      | 23        | 20       | 48                                        | 2                  | 4.0   | 28                                           | 19      |
| 20      | Nov. 6    | Dec. 4   | 44                                        | 3                  | 5.0   | 28                                           | 17      |
| 21      | 20        | 18       | 48                                        | 4                  | 6.0   | 24                                           | 14      |
|         |           | 1917     |                                           |                    |       |                                              |         |
| 22      | Dec. 4    | Jan. 1   | 50                                        | 4                  | 6.0   | 25                                           | 11      |
| 23      | 18        | 15       | 48                                        | 5                  | 7.0   | 28                                           | 9       |
|         | 1917      |          |                                           |                    |       |                                              |         |
| 24      | Jan. 1    | 29       | 48                                        | 5                  | 7.0   | 32                                           | 9       |
| 25      | 15        | Feb. 12  | 47                                        | 5                  | 7.0   | 29                                           | 8       |
| 26      | 29        | 26       | 53                                        | 6                  | 8.0   | 18                                           | 7       |
| 27      | Feb. 12   | Mar. 12  | 72                                        | 5                  | 8.0   | 33                                           | 10      |

<sup>a</sup>The germination period always preceded the period shown in the first two columns.

<sup>b</sup>Not recorded for sets 1-5.



TABLE II.

*Data showing average number of leaves per plant (omitting cotyledons)  
for exposed and sheltered series.*

| 4-week<br>period<br>ending | Average number of leaves at end of |        |           |        |           |        |           |        |
|----------------------------|------------------------------------|--------|-----------|--------|-----------|--------|-----------|--------|
|                            | 1st. week                          |        | 2nd. week |        | 3rd. week |        | 4th. week |        |
|                            | Exp.                               | Shelt. | Exp.      | Shelt. | Exp.      | Shelt. | Exp.      | Shelt. |
| <i>1916</i>                |                                    |        |           |        |           |        |           |        |
| Mar. 13                    | 1.1                                | 1.1    | 2.9       | 2.2    | 6.2       | 3.7    | 11.2      | 7.4    |
| 27                         | 0.6                                | 0.6    | 2.3       | 2.0    | 7.3       | 4.0    | 13.9      | 7.6    |
| Apr. 10                    | 1.0                                | 1.0    | 3.6       | 2.4    | 9.3       | 4.8    | 15.1      | 7.4    |
| 24                         | 1.0                                | 0.8    | 2.9       | 2.1    | 11.3      | 6.7    | 15.3      | 11.0   |
| May 8                      | 1.0                                | 1.0    | 3.7       | 3.3    | 10.1      | 6.8    | 15.3      | 12.8   |
| 22                         | 0.9                                | 0.9    | 3.7       | 2.9    | 8.8       | 5.4    | 14.6      | 11.5   |
| June 5                     | 1.0                                | 1.0    | 2.4       | 2.2    | 6.4       | 4.0    | 13.0      | 7.9    |
| 19                         | 1.0                                | 0.9    | 3.0       | 2.3    | 5.4       | 4.1    | 10.3      | 7.8    |
| July 3                     | 1.0                                | 1.0    | 2.6       | 2.3    | 4.7       | 4.3    | 9.5       | 7.1    |
| 17                         | 1.0                                | 1.0    | 3.1       | 2.8    | 5.4       | 4.8    | 7.4       | 9.6    |
| 31                         | 1.2                                | 1.0    | 3.3       | 2.8    | 5.1       | 4.4    | 8.6       | 6.1    |
| Aug. 14                    | 1.6                                | 1.0    | 3.6       | 2.6    | 7.1       | 4.3    | 12.8      | 6.2    |
| 28                         | 1.2                                | 1.1    | 3.1       | 2.4    | 7.9       | 4.5    | 14.4      | 7.9    |
| Sept. 11                   | a                                  | 1.0    | a         | 2.4    | a         | 4.8    | a         | 8.7    |
| 25                         | 1.0                                | 1.0    | 3.5       | 2.6    | 9.7       | 5.1    | 12.3      | 7.5    |
| Oct. 9                     | 0.9                                | 0.9    | 2.7       | 2.4    | 6.4       | 4.2    | 9.8       | 6.9    |
| 23                         | 0.3                                | 0.0    | 2.5       | 2.0    | 5.2       | 3.1    | 8.5       | 4.5    |
| Nov. 6                     | 0.0                                | 0.0    | 1.7       | 1.0    | 5.5       | 3.2    | 9.8       | 4.2    |
| 20                         | 1.0                                | 0.7    | 2.9       | 2.1    | 6.2       | 3.9    | 7.0       | 4.3    |
| Dec. 4                     | 1.0                                | 0.4    | 2.7       | 1.3    | 4.6       | 2.7    | 7.0       | 3.9    |
| 18                         | 0.4                                | 0.0    | 2.2       | 1.4    | 4.2       | 2.7    | 5.6       | 3.5    |
| <i>1917</i>                |                                    |        |           |        |           |        |           |        |
| Jan. 1                     | 0.0                                | 0.0    | 1.7       | 0.1    | 3.5       | 2.2    | 4.9       | 3.1    |
| 15                         | 0.0                                | 0.0    | 1.3       | 1.0    | 3.1       | 1.9    | 4.0       | 3.0    |
| 29                         | 0.0                                | 0.0    | 1.2       | 0.6    | 2.8       | 1.7    | 4.4       | 2.3    |
| Feb. 12                    | 0.0                                | 0.0    | 1.2       | 0.9    | 2.7       | 1.5    | 4.3       | 2.8    |
| 26                         | 0.0                                | 0.0    | 1.0       | 0.9    | 2.8       | 2.0    | 4.1       | 3.2    |
| Mar. 12                    | 0.7                                | 0.0    | 2.1       | 1.3    | 4.4       | 2.3    | 6.8       | 3.5    |

a. Data not obtained because of insect injury to plants.

TABLE III.

*Data showing average number of flowers and seeds per plant for each set of the exposed and sheltered series.*

| 4-wk. period<br>ending | No. of flowers at end of |        |                    |                   |              |        |
|------------------------|--------------------------|--------|--------------------|-------------------|--------------|--------|
|                        | 3rd. week                |        | 4th. week          |                   | No. of seeds |        |
|                        | Exp.                     | Shelt. | Exp.               | Shelt.            | Exp.         | Shelt. |
| March 13               | 0.1                      | 0.0    | 14.7               | 8.8               | 0.0          | 0.0    |
| 27                     | 0.0                      | 0.0    | 20.9               | 7.6               | 0.0          | 0.0    |
| April 10               | 1.2                      | 0.2    | 49.9               | 20.2              | 0.0          | 0.0    |
| 24                     | 2.6                      | 0.0    | 100.6              | 38.4              | 0.0          | 0.0    |
| May 8                  | 2.6                      | 1.5    | 100.0 <sup>a</sup> | 40.0 <sup>a</sup> | 4.8          | 0.0    |
| 22                     | 2.0                      | 0.5    | 77.0 <sup>a</sup>  | 30.0 <sup>a</sup> | 0.1          | 0.0    |
| June 5                 | 0.0                      | 0.0    | 50.0 <sup>a</sup>  | 10.0 <sup>a</sup> | 0.0          | 0.0    |
| 19                     | 0.0                      | 0.0    | 3.3                | 0.3               | 0.0          | 0.0    |
| July 3                 | 0.0                      | 0.0    | 1.5                | 5.0 <sup>a</sup>  | 0.0          | 0.0    |
| 17                     | 0.0                      | 0.0    | 0.5                | 2.5               | 0.0          | 0.0    |
| 31                     | 0.0                      | 0.0    | 6.0                | 0.0               | 0.0          | 0.0    |
| Aug. 14                | 1.4                      | 0.0    | 20.0 <sup>a</sup>  | 0.1               | 0.0          | 0.0    |
| 28                     | 1.1                      | 0.0    | 70.0 <sup>a</sup>  | 10.0?             | 0.0          | 0.0    |
| Sept. 11               | <sup>b</sup>             | 0.3    | <sup>b</sup>       | 40.0?             | <sup>b</sup> | 0.0    |
| 25                     | 6.6                      | 1.3    | 120.0 <sup>a</sup> | 30.0?             | 21.6         | 1.0    |
| Oct. 9                 | 0.0                      | 0.0    | 20.0 <sup>a</sup>  | 12.3              | 3.4          | 0.0    |
| 23                     | 0.0                      | 0.0    | 7.8                | 3.9               | 0.1          | 0.0    |
| Nov. 6                 | 0.0                      | 0.0    | 17.4               | 5.4               | 0.6          | 0.0    |
| 20                     | 3.8                      | 0.1    | 50.0 <sup>a</sup>  | 8.9               | 9.7          | 0.0    |
| Dec. 4                 | 0.5                      | 0.0    | 15.6               | 2.5               | 4.5          | 0.0    |
| 18                     | 0.0                      | 0.0    | 5.8                | 0.9               | 0.0          | 0.0    |
| <i>1917</i>            |                          |        |                    |                   |              |        |
| Jan. 1                 | 0.0                      | 0.0    | 1.4                | 0.0               | 0.0          | 0.0    |
| 15                     | 0.0                      | 0.0    | 2.5                | 0.0               | 0.0          | 0.0    |
| 29                     | 0.0                      | 0.0    | 0.4                | 0.0               | 0.0          | 0.0    |
| Feb. 12                | 0.0                      | 0.0    | 0.6                | 0.0               | 0.0          | 0.0    |
| 26                     | 0.0                      | 0.0    | 0.1                | 0.0               | 0.0          | 0.0    |
| Mar. 12                | 0.2                      | 0.0    | 11.2               | 0.4               | 0.0          | 0.0    |

<sup>a</sup>Estimated number.

<sup>b</sup>Data not obtained because of insect injury to plants.



TABLE IV.

*Data showing the average plant height for each set of the exposed and sheltered series.*

| 4-week<br>period<br>ending | Ave. initial<br>height of<br>seedlings. |            | Average height at end of |            |            |            |            |            |            |            |
|----------------------------|-----------------------------------------|------------|--------------------------|------------|------------|------------|------------|------------|------------|------------|
|                            |                                         |            | 1st. week                |            | 2nd. week  |            | 3rd. week  |            | 4th. week  |            |
|                            | Exp.                                    | Shelt.     | Exp.                     | Shelt.     | Exp.       | Shelt.     | Exp.       | Shelt.     | Exp.       | Shelt.     |
| <i>1916</i>                | <i>cm.</i>                              | <i>cm.</i> | <i>cm.</i>               | <i>cm.</i> | <i>cm.</i> | <i>cm.</i> | <i>cm.</i> | <i>cm.</i> | <i>cm.</i> | <i>cm.</i> |
| Mar. 13                    | 2.0                                     | 2.2        | 6.9                      | 9.8        | 13.3       | 15.5       | 30.3       | 30.9       | 49.3       | 49.1       |
| 27                         | 3.1                                     | 2.8        | 8.8                      | 10.8       | 14.0       | 16.4       | 27.7       | 29.7       | 55.9       | 54.8       |
| Apr. 10                    | 1.9                                     | 1.8        | 5.7                      | 7.0        | 16.3       | 16.8       | 40.4       | 37.4       | 57.5       | 58.9       |
| 24                         | 2.6                                     | 2.7        | 8.9                      | 10.2       | 16.6       | 17.0       | 42.9       | 37.9       | 63.7       | 61.8       |
| May 8                      | 1.8                                     | 1.6        | 6.0                      | 8.8        | 17.7       | 20.0       | 42.5       | 40.7       | 66.1       | 68.2       |
| 22                         | 1.5                                     | 1.5        | 7.7                      | 9.8        | 19.2       | 20.8       | 44.8       | 42.3       | 67.5       | 65.2       |
| June 5                     | 1.2                                     | 1.3        | 7.8                      | 9.6        | 15.7       | 18.3       | 38.8       | 38.4       | 62.5       | 59.7       |
| 19                         | 0.6                                     | 0.5        | 6.8                      | 8.7        | 16.8       | 17.5       | 34.6       | 32.6       | 55.7       | 55.7       |
| July 3                     | 2.0                                     | 2.1        | 6.8                      | 10.2       | 15.8       | 19.0       | 33.8       | 37.5       | 49.0       | 57.1       |
| 17                         | 1.9                                     | 1.9        | 9.0                      | 11.4       | 19.3       | 22.2       | 37.3       | 39.2       | 52.2       | 60.9       |
| 31                         | 1.7                                     | 1.8        | 9.1                      | 11.0       | 21.2       | 21.8       | 43.2       | 37.5       | 65.4       | 55.7       |
| Aug. 14                    | 2.5                                     | 2.5        | 11.6                     | 14.1       | 25.6       | 25.2       | 51.0       | 43.7       | 70.3       | 61.0       |
| 28                         | 2.2                                     | 1.9        | 10.7                     | 12.9       | 20.7       | 20.2       | 41.6       | 35.9       | 61.1       | 56.9       |
| Sept 11                    | 2.6                                     | 2.6        | 10.7                     | 13.0       | 18.5       | 22.7       | a          | 40.5       | a          | 61.3       |
| 25                         | 1.8                                     | 2.0        | 9.7                      | 13.6       | 23.4       | 24.4       | 50.4       | 44.3       | 72.5       | 67.0       |
| Oct. 9                     | 1.7                                     | 1.8        | 10.0                     | 11.5       | 19.7       | 20.6       | 40.6       | 37.1       | 65.6       | 59.5       |
| 23                         | 1.6                                     | 1.4        | 7.5                      | 10.4       | 18.0       | 21.5       | 32.7       | 34.8       | 52.9       | 49.3       |
| Nov. 6                     | 1.5                                     | 1.4        | 7.7                      | 9.7        | 14.1       | 16.3       | 31.1       | 30.2       | 53.1       | 47.5       |
| 20                         | 1.6                                     | 1.5        | 10.2                     | 13.1       | 20.6       | 22.1       | 37.5       | 36.3       | 51.7       | 46.5       |
| Dec. 4                     | 2.7                                     | 2.7        | 9.0                      | 12.7       | 16.9       | 18.0       | 28.6       | 28.3       | 43.2       | 40.3       |
| 18                         | 2.4                                     | 2.5        | 8.3                      | 9.7        | 16.4       | 16.5       | 30.0       | 26.5       | 41.8       | 35.8       |
| <i>1917</i>                |                                         |            |                          |            |            |            |            |            |            |            |
| Jan. 1                     | 1.2                                     | 1.2        | 8.8                      | 10.4       | 13.7       | 14.8       | 25.9       | 25.5       | 38.8       | 35.3       |
| 15                         | 2.0                                     | 2.0        | 9.2                      | 9.8        | 14.7       | 13.9       | 29.2       | 21.9       | 40.8       | 30.3       |
| 29                         | 1.2                                     | 1.2        | 8.5                      | 9.1        | 12.4       | 13.0       | 20.6       | 20.2       | 29.7       | 27.9       |
| Feb. 12                    | 1.0                                     | 0.9        | 7.4                      | 9.1        | 13.3       | 13.7       | 20.8       | 19.8       | 26.2       | 27.6       |
| 26                         | 0.4                                     | 0.4        | 5.7                      | 8.3        | 10.9       | 12.9       | 19.3       | 20.5       | 29.4       | 28.7       |
| Mar. 12                    | 1.7                                     | 1.9        | 7.8                      | 9.8        | 14.9       | 16.1       | 25.6       | 24.3       | 32.5       | 32.7       |

<sup>a</sup>Data not obtained because of insect injury to plants.

TABLE V.

*Data showing average number of branches, average total length of branches and average total cylindrical portion formed per plant for each set of the exposed and sheltered series.*

| ending<br>period<br>4-week | Number of<br>branches |        | Total length<br>of branches |            | Total length<br>of cylindrical<br>portion <sup>a</sup> |            |
|----------------------------|-----------------------|--------|-----------------------------|------------|--------------------------------------------------------|------------|
|                            | Exp.                  | Shelt. | Exp.                        | Shelt.     | Exp.                                                   | Shelt.     |
| <i>1916</i>                |                       |        | <i>cm.</i>                  | <i>cm.</i> | <i>cm.</i>                                             | <i>cm.</i> |
| Mar. 13                    | ...                   | ...    | ....                        | ....       | ....                                                   | ....       |
| 27                         | ...                   | ...    | ....                        | ....       | ....                                                   | ....       |
| Apr. 10                    | 3.8                   | 2.6    | 43.2                        | 6.7        | 100.7                                                  | 65.6       |
| 24                         | 4.5                   | 3.7    | 46.7                        | 17.1       | 110.4                                                  | 78.9       |
| May 8                      | 5.3                   | 5.0    | 35.3                        | 20.3       | 101.4                                                  | 88.5       |
| 22                         | 5.8                   | 4.7    | 23.9                        | 12.4       | 91.4                                                   | 77.6       |
| June 5                     | 5.4                   | 2.6    | 17.4                        | 3.5        | 79.9                                                   | 63.2       |
| 19                         | 4.1                   | 2.2    | 9.0                         | 1.6        | 64.7                                                   | 57.3       |
| July 3                     | 3.0                   | 2.0    | 3.8                         | 2.8        | 52.8                                                   | 59.9       |
| 17                         | 3.0                   | 1.1    | 4.2                         | 1.6        | 56.4                                                   | 62.5       |
| 31                         | 2.1                   | 0.2    | 4.5                         | 0.3        | 69.9                                                   | 56.0       |
| Aug. 14                    | 4.9                   | 0.9    | 15.3                        | 1.0        | 85.6                                                   | 62.0       |
| 28                         | 5.9                   | 2.9    | 17.2                        | 4.5        | 78.3                                                   | 61.4       |
| Sept 11                    | b                     | 4.0    | b                           | 8.3        | b                                                      | 69.6       |
| 25                         | 5.7                   | 3.4    | 31.1                        | 7.0        | 103.6                                                  | 74.0       |
| Oct. 9                     | 5.0                   | 3.4    | 21.2                        | 2.9        | 86.8                                                   | 62.4       |
| 23                         | 3.9                   | 2.3    | 8.8                         | 1.1        | 61.7                                                   | 50.4       |
| Nov. 6                     | 5.2                   | 0.7    | 17.1                        | 0.5        | 70.2                                                   | 48.0       |
| 20                         | 3.3                   | 0.9    | 5.9                         | 0.7        | 57.6                                                   | 47.2       |
| Dec. 4                     | 2.8                   | 0.7    | 3.4                         | 0.4        | 46.6                                                   | 40.7       |
| 18                         | 1.5                   | 0.1    | 0.9                         | 0.1        | 42.7                                                   | 35.9       |
| <i>1917</i>                |                       |        |                             |            |                                                        |            |
| Jan. 1                     | 1.0                   | 0.0    | 0.4                         | 0.0        | 39.2                                                   | 35.3       |
| 15                         | 0.5                   | 0.0    | 0.2                         | 0.0        | 41.0                                                   | 30.3       |
| 29                         | 0.3                   | 0.0    | 0.3                         | 0.0        | 30.0                                                   | 27.9       |
| Feb. 12                    | 0.8                   | 0.0    | 0.4                         | 0.0        | 26.6                                                   | 27.6       |
| 26                         | 0.0                   | 0.0    | 0.0                         | 0.0        | 29.4                                                   | 28.7       |
| Mar. 12                    | 2.7                   | 0.0    | 2.4                         | 0.0        | 34.9                                                   | 32.7       |

<sup>a</sup>Sum of height *plus* total length of branches.

<sup>b</sup>Data not obtained because of insect injury to plants.

TABLE VI.

*Data showing average total transpiration per plant for each set of the exposed and sheltered series.*

| 4-week<br>period<br>ending | Average transpirational water loss per plant for |              |              |              |              |              |              |              |
|----------------------------|--------------------------------------------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
|                            | First week                                       |              | First 2 wks. |              | First 3 wks. |              | First 4 wks. |              |
|                            | Exp.                                             | Shelt.       | Exp.         | Shelt.       | Exp.         | Shelt.       | Exp.         | Shelt.       |
| <i>1916</i>                | <i>grams</i>                                     | <i>grams</i> | <i>grams</i> | <i>grams</i> | <i>grams</i> | <i>grams</i> | <i>grams</i> | <i>grams</i> |
| Mar. 13                    | 8.8                                              | 6.6          | 29.8         | 19.2         | 85.3         | 49.4         | 192.4        | 104.3        |
| 27                         | 8.2                                              | 5.7          | 37.1         | 23.8         | 98.5         | 58.0         | 242.5        | 137.1        |
| Apr. 10                    | 9.2                                              | 6.2          | 46.3         | 25.8         | 132.0        | 65.4         | 270.1        | 132.9        |
| 24                         | 10.5                                             | 6.4          | 49.9         | 25.8         | 179.1        | 88.7         | 372.1        | 211.0        |
| May 8                      | 13.4                                             | 9.7          | 71.5         | 45.8         | 183.2        | 108.9        | 375.4        | 246.5        |
| 22                         | 14.5                                             | 8.5          | 90.9         | 47.4         | 210.9        | 110.4        | 388.8        | 227.8        |
| June 5                     | 12.1                                             | 8.4          | 59.0         | 36.2         | 160.8        | 104.5        | 359.7        | 241.7        |
| 19                         | 14.6                                             | 9.4          | 88.4         | 50.5         | 184.0        | 107.7        | 343.8        | 230.9        |
| July 3                     | 12.0                                             | 8.3          | 61.6         | 38.6         | 201.6        | 138.2        | 367.8        | 284.5        |
| 17                         | 21.2                                             | 15.4         | 98.7         | 63.7         | 242.5        | 158.7        | 405.7        | 306.7        |
| 31                         | 16.6                                             | 12.6         | 69.2         | 45.4         | 214.8        | 124.8        | 398.0        | 245.2        |
| Aug. 14                    | 22.8                                             | 14.4         | 88.2         | 47.4         | 229.4        | 126.9        | 399.0        | 263.5        |
| 28                         | 21.6                                             | 14.6         | 71.0         | 38.5         | 230.8        | 107.6        | 401.4        | 210.0        |
| Sept 11                    | 20.0                                             | 13.8         | 49.6         | 43.3         | a            | 98.4         | a            | 204.4        |
| 25                         | 16.1                                             | 9.9          | 81.1         | 42.5         | 174.3        | 85.6         | 338.9        | 157.8        |
| Oct. 9                     | 9.8                                              | 7.3          | 43.9         | 28.9         | 101.7        | 62.9         | 202.0        | 115.8        |
| 23                         | 7.5                                              | 5.7          | 31.8         | 21.1         | 61.9         | 37.3         | 134.4        | 71.1         |
| Nov. 6                     | 4.8                                              | 3.4          | 25.0         | 16.1         | 73.8         | 42.3         | 167.6        | 80.4         |
| 20                         | 9.3                                              | 6.0          | 30.4         | 17.8         | 74.1         | 38.8         | 122.1        | 61.1         |
| Dec. 4                     | 7.9                                              | 5.6          | 24.1         | 14.5         | 51.1         | 27.7         | 87.0         | 40.3         |
| 18                         | 6.2                                              | 4.7          | 17.7         | 10.2         | 45.6         | 24.0         | 77.4         | 36.5         |
| <i>1917</i>                |                                                  |              |              |              |              |              |              |              |
| Jan. 1                     | 5.5                                              | 3.9          | 14.1         | 8.6          | 36.6         | 19.2         | 65.1         | 30.1         |
| 15                         | 5.3                                              | 3.3          | 14.9         | 7.5          | 33.2         | 15.5         | 57.2         | 23.3         |
| 29                         | 4.0                                              | 3.2          | 9.4          | 5.9          | 21.3         | 11.9         | 40.2         | 19.0         |
| Feb. 12                    | 3.8                                              | 2.8          | 11.0         | 6.8          | 26.4         | 15.5         | 47.5         | 24.2         |
| 26                         | 4.4                                              | 2.9          | 11.9         | 7.0          | 24.9         | 12.5         | 58.0         | 23.9         |
| Mar. 12                    | 4.9                                              | 2.4          | 23.1         | 9.7          | 42.2         | 16.7         | 96.3         | 34.4         |

<sup>a</sup>Data not obtained because of insect injury to plants.



TABLE VII.

*Data showing average dry weights of top, roots and entire plant, and average total leaf area and cotyledon area per plant, for each set of the exposed and sheltered series, as obtained for the end of the 4-week period.*

| 4-week<br>period<br>ending |    | Dry weight |            |            |            |              |            | Total leaf<br>area<br>(one side) |                | Total area of<br>cotyledons |                |
|----------------------------|----|------------|------------|------------|------------|--------------|------------|----------------------------------|----------------|-----------------------------|----------------|
|                            |    | Top        |            | Roots      |            | Entire Plant |            |                                  |                |                             |                |
|                            |    | Exp.       | Shelt.     | Exp.       | Shelt.     | Exp.         | Shelt.     | Exp.                             | Shelt.         | Exp.                        | Shelt.         |
| <i>1916</i>                |    | <i>gr.</i> | <i>gr.</i> | <i>gr.</i> | <i>gr.</i> | <i>gr.</i>   | <i>gr.</i> | <i>sq. cm.</i>                   | <i>sq. cm.</i> | <i>sq. cm.</i>              | <i>sq. cm.</i> |
| Mar.                       | 13 | 0.621      | .338       | .052       | .022       | 0.673        | .360       | 135.4                            | 89.3           | 12.6                        | 12.5           |
|                            | 27 | 0.781      | .415       | .048       | .025       | 0.829        | .440       | 173.7                            | 106.5          | 16.5                        | 14.3           |
| Apr.                       | 10 | 0.904      | .428       | .057       | .024       | 0.961        | .452       | 165.1                            | 88.5           | 15.7                        | 13.2           |
|                            | 24 | 1.019      | .592       | .055       | .032       | 1.074        | .624       | 162.8                            | 120.1          | 13.3                        | 12.1           |
| May                        | 8  | 1.105      | .634       | .080       | .035       | 1.185        | .729       | 162.8                            | 125.9          | 11.1                        | 11.3           |
|                            | 22 | 1.229      | .726       | .109       | .036       | 1.338        | .762       | 213.5                            | 155.9          | 13.7                        | 13.4           |
| June                       | 5  | 1.117      | .746       | .095       | .038       | 1.212        | .784       | 198.1                            | 143.8          | 14.4                        | 14.2           |
|                            | 19 | 1.142      | .717       | .098       | .041       | 1.249        | .758       | 208.5                            | 174.1          | 9.7                         | 13.3           |
| July                       | 3  | 1.153      | .839       | .090       | .042       | 1.243        | .881       | 214.1                            | 184.3          | 17.0                        | 14.9           |
|                            | 17 | 1.111      | .746       | .063       | .039       | 1.174        | .785       | 187.0                            | 212.5          | 11.7                        | 8.9            |
|                            | 31 | 1.161      | .589       | .057       | .030       | 1.218        | .619       | 195.5                            | 134.0          | 12.6                        | 11.6           |
| Aug.                       | 14 | 1.052      | .571       | .049       | .030       | 1.101        | .601       | 176.8                            | 133.3          | 9.0                         | 10.2           |
|                            | 28 | 0.855      | .400       | .047       | .023       | 0.902        | .423       | 164.5                            | 95.0           | 10.4                        | 6.0            |
| Sept.                      | 11 | a          | .438       | a          | .022       | a            | .460       | a                                | 96.8           | a                           | 11.0           |
|                            | 25 | 0.965      | .408       | .048       | .019       | 1.013        | .427       | 149.1                            | 86.7           | 13.8                        | 12.1           |
| Oct.                       | 9  | 0.703      | .349       | .032       | .016       | 0.735        | .365       | 123.8                            | 85.0           | 15.2                        | 14.0           |
|                            | 23 | 0.421      | .212       | .029       | .010       | 0.450        | .222       | 92.2                             | 56.7           | 12.5                        | 12.6           |
| Nov.                       | 6  | 0.461      | .179       | .025       | .008       | 0.486        | .187       | 108.9                            | 53.9           | 16.3                        | 14.1           |
|                            | 20 | 0.313      | .138       | .014       | .004       | 0.327        | .142       | 75.0                             | 41.0           | 11.8                        | 9.8            |
| Dec.                       | 4  | 0.273      | .110       | .014       | .004       | 0.287        | .114       | 71.6                             | 37.3           | 13.4                        | 11.1           |
|                            | 18 | 0.238      | .086       | .011       | .003       | 0.249        | .089       | 65.1                             | 31.4           | 12.8                        | 10.0           |
| <i>1917</i>                |    |            |            |            |            |              |            |                                  |                |                             |                |
| Jan.                       | 1  | 0.212      | .087       | .014       | .004       | 0.226        | .091       | 66.9                             | 32.0           | 13.1                        | 11.0           |
|                            | 15 | 0.183      | .062       | .010       | .003       | 0.193        | .065       | 59.6                             | 24.5           | 14.2                        | 10.0           |
|                            | 29 | 0.106      | .044       | .006       | .002       | 0.112        | .046       | 40.3                             | 16.7           | 10.7                        | 8.3            |
| Feb.                       | 12 | 0.134      | .059       | .008       | .004       | 0.142        | .063       | 42.8                             | 22.3           | 12.8                        | 10.2           |
|                            | 26 | 0.151      | .050       | .009       | .002       | 0.160        | .052       | 52.3                             | 19.2           | 13.0                        | 8.4            |
| Mar.                       | 12 | 0.228      | .074       | .016       | .004       | 0.244        | .078       | 66.1                             | 24.8           | 13.2                        | 9.2            |

<sup>a</sup>Data not obtained because of insect injury to plants.

TABLE VIII.

*General notes on abnormalities of plants in various sets of the exposed and sheltered series.*

|                    |    | Remarks                                                                    |                                                                           |
|--------------------|----|----------------------------------------------------------------------------|---------------------------------------------------------------------------|
| Period ending 1916 |    | Exposed Series.                                                            | Sheltered Series.                                                         |
| Mar.               | 13 | 2 stems split.                                                             | 2 stems split. 1 pl. with adventitious roots. 1 pl. with blotched leaves. |
|                    | 27 |                                                                            |                                                                           |
| Apr.               | 10 |                                                                            |                                                                           |
|                    | 24 | 5 stems split.                                                             | 6 stems split.                                                            |
| May                | 8  | 2 stems split.                                                             | 1 stem split.                                                             |
|                    |    | 8 stems split.                                                             | 3 stems split.                                                            |
|                    |    | 1 stem split.                                                              | 2 stems split. 1 pl. with adventitious roots.                             |
|                    | 22 | 2 stems split.                                                             | 3 stems split.                                                            |
| June               | 5  | 3 stems split. 4 cotyl. dead.                                              | 2 stems split. 2 cotyl. dead.                                             |
|                    | 19 | 3 stems split. 1 pl. with lice. 2 pl. injured by wilting. -8 cotyl. dead.  | 3 stems split. 1 pl. with adventitious roots.                             |
| July               | 3  | 4 stems split. All plants short and thick. 1 pl. with leaves partly eaten. | 6 stems split. 1 cotyl. dead.                                             |
|                    | 17 | 3 stems split. 4 cotyl. dead. 3 partly burned.                             | 1 stem split. 2 cotyl. dead.                                              |
|                    | 31 | 1 stem split. 1 pl. with adventitious roots. 2 pls. dead. 1 cotyl. dead.   | 1 stem split. 1 cotyl. dead.                                              |
| Aug.               | 14 | 1 stem split. 4 cotyl. dead.                                               | 5 cotyl. dead.                                                            |
|                    | 28 | 1 stem split. 4 pls. partly burned. 4 plants with leaves eaten.            | 5 cotyl. dead.                                                            |
| Sept.              | 11 | 1 pl. dead.                                                                | 1 cotyl. dead.                                                            |
|                    | 25 |                                                                            | 2 stems split. 1 cotyl. dead.                                             |
| Oct.               | 9  | 3 stems split.                                                             |                                                                           |
|                    | 23 | 1 stem split.                                                              |                                                                           |
| Nov.               | 6  | 1 pl. eliminated. 2 stems split.                                           |                                                                           |
|                    | 20 | 1 stem split.                                                              | 2 stems split.                                                            |
| Dec.               | 4  |                                                                            | 1 cotyl. dead.                                                            |
|                    | 18 | 2 stems split.                                                             |                                                                           |
| 1917               |    |                                                                            |                                                                           |
| Jan.               | 1  | 1 stem split.                                                              |                                                                           |
|                    | 29 | 22 yellow leaves.                                                          | 19 yellow leaves. 2 leaves dead.                                          |
| Feb.               | 12 | 11 yellow leaves. 1 pl. dead. 2 dead leaves.                               | All leaves slightly yellow.                                               |
|                    | 26 | 8 yellow leaves. 2 pls. dead.                                              | 17 leaves yellow.                                                         |
| Mar.               | 12 | 8 yellow leaves. 1 stem split.                                             | 2 cotyl. dead. 5 yellow leaves. 1 leaf dead. 1 stem split.                |

of the areas of the *upper or lower* surfaces of all the leaves whose areas were greater than 0.5 sq. cm. The planimeter was read to 0.1 sq. cm. Each leaf was determined separately and the resulting values were then summed for each plant, after which the average value given in the table was obtained. The total cotyledon areas are given in the last double column of the table.

In table VIII appear some notes on the general appearances and on abnormalities of the plants in various culture sets of the two series.

*Instrumental data.* Table IX presents the weekly temperature values for each week, for each of the two series. The weekly maximum temperatures are given in the first double column and the weekly minimum temperatures in the second double column. The maximum and minimum temperatures for each day (read from the thermograph records) were averaged to give the daily mean temperature, while the difference between maximum and minimum represents the daily range. The daily means and daily ranges were averaged for each week to give the average daily mean and the average daily range, as recorded in the third and fourth double columns, respectively. In the last double column the weekly summations of the daily Livingston-Lehenbauer physiological temperature indices appear for each of the two environments. The daily indices corresponding to the daily means were taken from Livingston's<sup>10</sup> table of physiological indices. Each weekly value was obtained by summing these daily indices for that week.

Table X gives weekly data showing the evaporating power of the air as measured by the standard white spherical atmometer, and radiation as measured by the radio-atmometer, for each of the two series; also the approximate duration of sunshine for each week. These last-named values (derived from records of the Baltimore station of the U. S. Weather Bureau) represent the total number of hours of sunshine occurring in each week, as shown by the Marvin sunshine recorder.

*Summarized and derived plant and instrumental data.* Table XI contains data showing average stem height, total dry weight, total leaf area (one side) and transpiration per plant, expressed as relative numbers for each 4-week period of the exposed and sheltered series. All the values of any one particular kind of measurement in both series are expressed in terms of the corresponding kind of measurement for the culture set of the exposed series whose period ends March 13, 1916. These relative numbers facilitate comparison between any two periods in the same or in different series, for any

10—Livingston, B. E. Physiological temperature indices for the study of plant growth in relation to climatic conditions. *Physiol. Res.* 1: 399-420. 1916. (See especially p. 406.)



TABLE IX.

*Data showing weekly maximum and minimum temperatures, weekly averages of daily mean temperatures and of daily temperature ranges, and weekly summations of daily physiological indices, based on the corresponding daily means, for the exposed and sheltered series in each case.*

| Week<br>ending 12.01<br>a. m. | Temperature |        |        |        |                       |        |                        |        | Physiol.<br>index |        |
|-------------------------------|-------------|--------|--------|--------|-----------------------|--------|------------------------|--------|-------------------|--------|
|                               | Max.        |        | Min.   |        | Average<br>daily mean |        | Average<br>daily range |        |                   |        |
|                               | Exp.        | Shelt. | Exp.   | Shelt. | Exp.                  | Shelt. | Exp.                   | Shelt. |                   |        |
| 1916                          | deg. C      | deg. C | deg. C | deg. C | deg. C                | deg. C | deg. C                 | deg. C | deg. C            | deg. C |
| Feb. 21                       | 32          | 32     | 14     | 13     | 24                    | 24     | 12                     | 12     | 567               | 543    |
| 28                            | 31          | 31     | 16     | 15     | 22                    | 21     | 8                      | 8      | 463               | 461    |
| Mar. 6                        | 29          | 29     | 14     | 12     | 22                    | 21     | 11                     | 11     | 448               | 393    |
| 13                            | 29          | 28     | 13     | 11     | 21                    | 21     | 11                     | 10     | 399               | 369    |
| 20                            | 29          | 29     | 13     | 12     | 22                    | 20     | 10                     | 11     | 416               | 331    |
| 27                            | 33          | 32     | 16     | 17     | 24                    | 24     | 10                     | 12     | 557               | 559    |
| Apr. 3                        | 36          | 35     | 17     | 18     | 24                    | 23     | 8                      | 8      | 524               | 468    |
| 10                            | 29          | 30     | 15     | 14     | 21                    | 21     | 8                      | 9      | 401               | 382    |
| 17                            | 37          | 36     | 19     | 18     | 26                    | 26     | 12                     | 12     | 672               | 642    |
| 24                            | 39          | 38     | 19     | 19     | 26                    | 26     | 11                     | 11     | 657               | 660    |
| May 1                         | 39          | 38     | 19     | 18     | 23                    | 24     | 11                     | 10     | 591               | 547    |
| 8                             | 39          | 38     | 19     | 19     | 27                    | 27     | 14                     | 13     | 705               | 701    |
| 15                            | 36          | 36     | 15     | 15     | 24                    | 24     | 13                     | 13     | 524               | 531    |
| 22                            | 35          | 34     | 13     | 13     | 23                    | 23     | 15                     | 14     | 504               | 489    |
| 29                            | 40          | 39     | 16     | 16     | 25                    | 25     | 14                     | 13     | 595               | 579    |
| June 5                        | 37          | 36     | 15     | 15     | 26                    | 26     | 17                     | 15     | 672               | 650    |
| 12                            | 38          | 37     | 17     | 17     | 24                    | 24     | 12                     | 12     | 545               | 538    |
| 19                            | 39          | 38     | 17     | 17     | 26                    | 25     | 13                     | 13     | 627               | 608    |
| 26                            | 38          | 37     | 16     | 16     | 27                    | 27     | 15                     | 15     | 693               | 686    |
| July 3                        | 39          | 39     | 20     | 20     | 29                    | 29     | 15                     | 14     | 776               | 783    |
| 10                            | 43          | 42     | 18     | 18     | 30                    | 29     | 16                     | 15     | 797               | 790    |
| 17                            | 43          | 43     | 23     | 23     | 31                    | 31     | 13                     | 13     | 784               | 784    |
| 24                            | 42          | 41     | 24     | 24     | 31                    | 31     | 13                     | 13     | 834               | 833    |
| 31                            | 43          | 43     | 19     | 20     | 30                    | 30     | 14                     | 13     | 768               | 784    |
| Aug. 7                        | 42          | 40     | 20     | 20     | 31                    | 31     | 15                     | 14     | 802               | 811    |
| 14                            | 44          | 43     | 19     | 19     | 31                    | 30     | 14                     | 13     | 735               | 753    |
| 21                            | 41          | 40     | 17     | 17     | 29                    | 28     | 16                     | 16     | 766               | 754    |
| 28                            | 44          | 43     | 21     | 20     | 32                    | 31     | 18                     | 17     | 798               | 815    |

TABLE IX. (continued)

| Week<br>ending 12.01<br>a. m. | Temperature   |               |               |               |                       |               |                        |               | Physiol.<br>index |               |
|-------------------------------|---------------|---------------|---------------|---------------|-----------------------|---------------|------------------------|---------------|-------------------|---------------|
|                               | Max.          |               | Min.          |               | Average<br>daily mean |               | Average<br>daily range |               |                   |               |
|                               | Exp.          | Shelt.        | Exp.          | Shelt.        | Exp.                  | Shelt.        | Exp.                   | Shelt.        | Exp.              | Shelt.        |
| <i>1916</i>                   | <i>deg. C</i> | <i>deg. C</i> | <i>deg. C</i> | <i>deg. C</i> | <i>deg. C</i>         | <i>deg. C</i> | <i>deg. C</i>          | <i>deg. C</i> | <i>deg. C</i>     | <i>deg. C</i> |
| Sept. 4                       | 38            | 37            | 16            | 17            | 27                    | 27            | 16                     | 15            | 694               | 687           |
| 11                            | 41            | 40            | 17            | 17            | 28                    | 28            | 16                     | 15            | 747               | 752           |
| 18                            | 36            | 36            | 15            | 15            | 24                    | 25            | 14                     | 13            | 574               | 589           |
| 25                            | 38            | 35            | 14            | 13            | 24                    | 23            | 17                     | 16            | 573               | 520           |
| Oct. 2                        | 36            | 35            | 11            | 10            | 22                    | 22            | 15                     | 15            | 446               | 444           |
| 9                             | 35            | 35            | 11            | 10            | 23                    | 24            | 15                     | 15            | 509               | 530           |
| 16                            | 34            | 33            | 10            | 10            | 20                    | 20            | 15                     | 14            | 320               | 319           |
| 23                            | 33            | 33            | 10            | 10            | 22                    | 22            | 12                     | 11            | 438               | 439           |
| 30                            | 31            | 31            | 19            | 18            | 25                    | 25            | 10                     | 10            | 591               | 591           |
| Nov. 6                        | 33            | 32            | 19            | 20            | 25                    | 25            | 9                      | 8             | 626               | 611           |
| 13                            | 32            | 32            | 19            | 19            | 25                    | 24            | 9                      | 8             | 583               | 568           |
| 20                            | 29            | 28            | 13            | 13            | 22                    | 21            | 9                      | 8             | 420               | 388           |
| 27                            | 30            | 29            | 14            | 13            | 22                    | 21            | 10                     | 10            | 415               | 381           |
| Dec. 4                        | 28            | 26            | 16            | 15            | 21                    | 20            | 9                      | 8             | 374               | 349           |
| 11                            | 31            | 30            | 16            | 15            | 23                    | 22            | 8                      | 8             | 479               | 431           |
| 18                            | 31            | 28            | 11            | 10            | 20                    | 19            | 12                     | 10            | 326               | 259           |
| 25                            | 31            | 28            | 12            | 11            | 21                    | 19            | 11                     | 10            | 363               | 297           |
| <i>1917</i>                   |               |               |               |               |                       |               |                        |               |                   |               |
| Jan 1                         | 32            | 29            | 12            | 12            | 20                    | 19            | 9                      | 9             | 302               | 285           |
| 8                             | 31            | 29            | 15            | 15            | 22                    | 21            | 10                     | 9             | 416               | 365           |
| 15                            | 30            | 27            | 11            | 10            | 20                    | 19            | 11                     | 10            | 333               | 296           |
| 22                            | 30            | 29            | 12            | 12            | 20                    | 20            | 11                     | 10            | 345               | 318           |
| 29                            | 29            | 28            | 12            | 13            | 20                    | 20            | 11                     | 10            | 312               | 304           |
| Feb. 5                        | 32            | 30            | 7             | 7             | 20                    | 19            | 13                     | 12            | 312               | 283           |
| 12                            | 28            | 28            | 8             | 9             | 18                    | 19            | 14                     | 13            | 243               | 261           |
| 19                            | 31            | 30            | 7             | 8             | 20                    | 20            | 14                     | 13            | 352               | 336           |
| 26                            | 32            | 32            | 16            | 16            | 22                    | 23            | 10                     | 10            | 455               | 472           |
| Mar. 5                        | 29            | 29            | 15            | 15            | 21                    | 21            | 9                      | 8             | 383               | 359           |
| 12                            | 32            | 32            | 11            | 11            | 22                    | 23            | 12                     | 12            | 442               | 478           |

TABLE X.

*Data showing the weekly evaporating power of the air as measured by the standard white spherical atmometer, weekly radiation as measured by the radio-atmometer for the exposed and sheltered series, and weekly sunshine duration.*

| Week ending<br>12:01 a. m. | Evap. power of air<br>(weekly loss from white<br>spherical porous-cup<br>atmometer). |            | Radiation (dif. between<br>weekly loss from black<br>and white spheres). |            | Weekly<br>duration<br>of sun-<br>shine |
|----------------------------|--------------------------------------------------------------------------------------|------------|--------------------------------------------------------------------------|------------|----------------------------------------|
|                            | Exp.                                                                                 | Shelt.     | Exp.                                                                     | Shelt.     |                                        |
| <i>1916</i>                | <i>cc.</i>                                                                           | <i>cc.</i> | <i>cc.</i>                                                               | <i>cc.</i> | <i>hrs.</i>                            |
| Feb. 21                    | 156.0                                                                                | 111.3      | 18.4                                                                     | 9.3        | 49.8                                   |
| 28                         | 123.4                                                                                | 83.9       | 7.5                                                                      | 3.0        | 33.9                                   |
| Mar. 6                     | 146.8                                                                                | 107.2      | 17.3                                                                     | 7.3        | 43.8                                   |
| 13                         | 133.0                                                                                | 94.0       | 13.7                                                                     | 6.1        | 38.2                                   |
| 20                         | 135.6                                                                                | 97.0       | 17.4                                                                     | 6.6        | 51.9                                   |
| 27                         | 143.4                                                                                | 102.4      | 17.0                                                                     | 6.1        | 44.9                                   |
| Apr. 3                     | 126.0                                                                                | 92.8       | 17.7                                                                     | 7.2        | 30.2                                   |
| 10                         | 123.7                                                                                | 88.7       | 17.8                                                                     | 7.6        | 28.3                                   |
| 17                         | 168.4                                                                                | 128.4      | 36.9                                                                     | 12.5       | 63.5                                   |
| 24                         | 151.1                                                                                | 115.6      | 19.2                                                                     | 7.0        | 55.8                                   |
| May 1                      | 135.6                                                                                | 101.3      | 18.5                                                                     | 5.7        | 44.3                                   |
| 8                          | 136.7                                                                                | 112.3      | 23.6                                                                     | 7.0        | 60.4                                   |
| 15                         | 129.9                                                                                | 107.5      | 21.1                                                                     | 7.6        | 66.3                                   |
| 22                         | 106.2                                                                                | 87.1       | 23.3                                                                     | 7.9        | 69.9                                   |
| 29                         | 105.1                                                                                | 87.6       | 23.3                                                                     | 9.4        | 46.9                                   |
| June 5                     | 124.7                                                                                | 107.5      | 25.5                                                                     | 10.8       | 62.8                                   |
| 12                         | 91.2                                                                                 | 74.5       | 22.3                                                                     | 10.3       | 33.5                                   |
| 19                         | 97.2                                                                                 | 78.6       | 23.4                                                                     | 9.8        | 56.5                                   |
| 26                         | 141.5                                                                                | 114.3      | 35.4                                                                     | 13.7       | 66.2                                   |
| July 3                     | 107.6                                                                                | 86.8       | 24.5                                                                     | 9.7        | 66.2                                   |
| 10                         | 151.6                                                                                | 121.5      | 30.2                                                                     | 11.8       | 79.7                                   |
| 17                         | 102.5                                                                                | 85.3       | 26.5                                                                     | 10.3       | 56.8                                   |
| 24                         | 117.7                                                                                | 93.1       | 26.5                                                                     | 10.7       | 45.7                                   |
| 31                         | 102.4                                                                                | 81.7       | 24.1                                                                     | 8.9        | 46.7                                   |
| Aug. 7                     | 127.5                                                                                | 102.7      | 28.2                                                                     | 10.3       | 49.9                                   |
| 14                         | 130.9                                                                                | 102.7      | 25.8                                                                     | 10.1       | 59.6                                   |
| 21                         | 145.7                                                                                | 112.8      | 35.1                                                                     | 11.4       | 72.1                                   |
| 28                         | 132.9                                                                                | 105.3      | 26.1                                                                     | 9.1        | 80.2                                   |



TABLE X (continued)

| Week ending<br>12:01 a. m. | Evap. power of air<br>(weekly loss from white<br>spherical porous-cup<br>atmometer). |            | Radiation (dif. between<br>weekly loss from black<br>and white spheres). |            | Weekly<br>duration<br>of sun-<br>shine |
|----------------------------|--------------------------------------------------------------------------------------|------------|--------------------------------------------------------------------------|------------|----------------------------------------|
|                            | Exp.                                                                                 | Shelt.     | Exp.                                                                     | Shelt.     |                                        |
| <i>1916</i>                | <i>cc.</i>                                                                           | <i>cc.</i> | <i>cc.</i>                                                               | <i>cc.</i> | <i>hrs.</i>                            |
| Sept. 4                    | 129.2                                                                                | 102.0      | 26.2                                                                     | 8.3        | 64.6                                   |
| 11                         | 112.6                                                                                | 89.1       | 25.6                                                                     | 9.1        | 61.6                                   |
| 18                         | 91.6                                                                                 | 75.3       | 20.1                                                                     | 10.9       | 51.0                                   |
| 25                         | 87.7                                                                                 | 73.9       | 24.8                                                                     | 12.0       | 71.3                                   |
| Oct. 2                     | 83.7                                                                                 | 68.7       | 24.0                                                                     | 11.0       | 63.1                                   |
| 9                          | 68.4                                                                                 | 58.9       | 21.5                                                                     | 8.4        | 48.0                                   |
| 15                         | 72.3                                                                                 | 61.6       | 20.4                                                                     | 8.3        | 55.5                                   |
| 23                         | 83.8                                                                                 | 64.0       | 17.6                                                                     | 8.6        | 39.1                                   |
| 30                         | 138.0                                                                                | 102.5      | 23.1                                                                     | 12.9       | 65.9                                   |
| Nov. 6                     | 128.0                                                                                | 95.2       | 14.5                                                                     | 11.0       | 49.2                                   |
| 13                         | 124.3                                                                                | 90.4       | 15.3                                                                     | 11.5       | 47.6                                   |
| 20                         | 106.4                                                                                | 75.5       | 3.2                                                                      | 1.7        | 34.4                                   |
| 27                         | 122.0                                                                                | 89.8       | 6.7                                                                      | 3.1        | 46.6                                   |
| Dec. 4                     | 98.0                                                                                 | 68.9       | 3.3                                                                      | 0.7        | 30.6                                   |
| 11                         | 132.6                                                                                | 98.2       | 5.6                                                                      | 2.4        | 51.7                                   |
| 18                         | 109.2                                                                                | 77.0       | 4.0                                                                      | 0.7        | 29.0                                   |
| 25                         | 125.5                                                                                | 89.5       | 6.1                                                                      | 2.1        | 28.3                                   |
| <i>1917</i>                |                                                                                      |            |                                                                          |            |                                        |
| Jan. 1                     | 110.9                                                                                | 75.5       | 2.5                                                                      | 0.3        | 37.1                                   |
| 8                          | 113.6                                                                                | 80.8       | 3.3                                                                      | 1.2        | 28.6                                   |
| 15                         | 121.8                                                                                | 87.5       | 9.4                                                                      | 1.4        | 29.5                                   |
| 22                         | 122.0                                                                                | 88.0       | 10.2                                                                     | 2.9        | 34.0                                   |
| 29                         | 115.3                                                                                | 82.8       | 9.4                                                                      | 1.0        | 29.5                                   |
| Feb. 5                     | 119.2                                                                                | 87.5       | 12.0                                                                     | 2.8        | 39.5                                   |
| 12                         | 122.6                                                                                | 87.4       | 12.5                                                                     | 1.9        | 46.3                                   |
| 19                         | 121.5                                                                                | 85.7       | 11.4                                                                     | 1.5        | 39.4                                   |
| 26                         | 128.0                                                                                | 92.8       | 14.7                                                                     | 2.2        | 41.5                                   |
| Mar. 5                     | 97.9                                                                                 | 66.2       | 5.0                                                                      | 0.1        | 2.6                                    |
| 12                         | 154.8                                                                                | 114.3      | 22.3                                                                     | 3.2        | 58.0                                   |

TABLE XI.

*Data showing stem height, total dry weight, total leaf area and transpiration per plant, expressed as relative numbers for each four-week period of the exposed and sheltered series.*

| 4-week<br>period<br>ending | Stem height           |        | Total dry<br>weight |        | Total<br>leaf area<br>(one side) |        | Transpiration         |        |
|----------------------------|-----------------------|--------|---------------------|--------|----------------------------------|--------|-----------------------|--------|
|                            | Exp.                  | Shelt. | Exp.                | Shelt. | Exp.                             | Shelt. | Exp.                  | Shelt. |
| <i>1916</i>                |                       |        |                     |        |                                  |        |                       |        |
| Mar. 13                    | 1.00<br>(49.3<br>cm.) | 1.00   | 1.00<br>(.673g.)    | .54    | 1.00<br>(135.4<br>sq. cm.)       | .66    | 1.00<br>(192.4<br>g.) | .54    |
| 27                         | 1.13                  | 1.11   | 1.23                | .65    | 1.28                             | .79    | 1.26                  | .71    |
| Apr. 10                    | 1.17                  | 1.20   | 1.43                | .67    | 1.22                             | .65    | 1.40                  | .69    |
| 24                         | 1.29                  | 1.25   | 1.60                | .93    | 1.20                             | .89    | 1.93                  | 1.10   |
| May 8                      | 1.34                  | 1.38   | 1.76                | 1.08   | 1.20                             | .93    | 1.95                  | 1.28   |
| 22                         | 1.37                  | 1.32   | 1.99                | 1.13   | 1.58                             | 1.15   | 2.02                  | 1.18   |
| June 5                     | 1.27                  | 1.21   | 1.80                | 1.16   | 1.46                             | 1.06   | 1.87                  | 1.26   |
| 19                         | 1.13                  | 1.13   | 1.84                | 1.13   | 1.54                             | 1.29   | 1.79                  | 1.20   |
| July 3                     | .99                   | 1.16   | 1.85                | 1.31   | 1.58                             | 1.36   | 1.91                  | 1.48   |
| 17                         | 1.06                  | 1.24   | 1.74                | 1.17   | 1.38                             | 1.57   | 2.11                  | 1.59   |
| 31                         | 1.33                  | 1.13   | 1.81                | .92    | 1.44                             | .99    | 2.07                  | 1.28   |
| Aug. 14                    | 1.43                  | 1.24   | 1.64                | .89    | 1.31                             | .99    | 2.07                  | 1.37   |
| 28                         | 1.24                  | 1.15   | 1.34                | .63    | 1.21                             | .70    | 2.09                  | 1.09   |
| Sept. 11                   | a                     | 1.24   | a                   | .69    | a                                | .72    | a                     | 1.06   |
| 25                         | 1.47                  | 1.36   | 1.51                | .63    | 1.10                             | .64    | 1.76                  | .82    |
| Oct. 9                     | 1.33                  | 1.21   | 1.09                | .54    | .91                              | .63    | 1.05                  | .60    |
| 23                         | 1.07                  | 1.00   | .67                 | .33    | .68                              | .42    | .70                   | .37    |
| Nov. 6                     | 1.08                  | .96    | .72                 | .28    | .80                              | .40    | .87                   | .42    |
| 20                         | 1.05                  | .94    | .49                 | .21    | .55                              | .30    | .63                   | .32    |
| Dec. 4                     | .88                   | .82    | .43                 | .17    | .53                              | .28    | .45                   | .21    |
| 18                         | .85                   | .73    | .37                 | .13    | .48                              | .23    | .40                   | .19    |
| <i>1917</i>                |                       |        |                     |        |                                  |        |                       |        |
| Jan. 1                     | .79                   | .72    | .34                 | .14    | .49                              | .24    | .34                   | .16    |
| 15                         | .83                   | .61    | .29                 | .10    | .44                              | .18    | .30                   | .12    |
| 29                         | .60                   | .57    | .17                 | .07    | .30                              | .12    | .21                   | .10    |
| Feb. 12                    | .53                   | .56    | .21                 | .09    | .32                              | .16    | .25                   | .13    |
| 26                         | .60                   | .58    | .24                 | .08    | .39                              | .14    | .30                   | .12    |
| Mar. 12                    | .66                   | .66    | .36                 | .12    | .49                              | .18    | .50                   | .18    |

a Data not obtained because of insect injury to plants.

TABLE XII.

*Data showing maximum and minimum temperatures, average daily mean temperature and average daily temperature range, for each four-week period of the exposed and sheltered series.*

| 4-week<br>period<br>ending | Minimum<br>for period |              | Maximum<br>for period |              | Average<br>daily mean |              | Average<br>daily range |              |
|----------------------------|-----------------------|--------------|-----------------------|--------------|-----------------------|--------------|------------------------|--------------|
|                            | Exp.                  | Shelt.       | Exp.                  | Shelt.       | Exp.                  | Shelt.       | Exp.                   | Shelt.       |
| <i>1916</i>                | <i>deg.C</i>          | <i>deg.C</i> | <i>deg.C</i>          | <i>deg.C</i> | <i>deg.C</i>          | <i>deg.C</i> | <i>deg.C</i>           | <i>deg.C</i> |
| Mar. 13                    | 32                    | 32           | 13                    | 11           | 23                    | 22           | 10                     | 10           |
| 27                         | 33                    | 32           | 13                    | 11           | 22                    | 22           | 10                     | 11           |
| Apr. 10                    | 36                    | 35           | 13                    | 12           | 23                    | 22           | 9                      | 10           |
| 24                         | 39                    | 38           | 15                    | 14           | 24                    | 24           | 10                     | 10           |
| May 8                      | 39                    | 38           | 19                    | 18           | 26                    | 26           | 12                     | 12           |
| 22                         | 39                    | 38           | 13                    | 13           | 25                    | 24           | 13                     | 13           |
| June 5                     | 40                    | 39           | 13                    | 13           | 25                    | 24           | 14                     | 14           |
| 19                         | 40                    | 39           | 15                    | 15           | 25                    | 25           | 14                     | 13           |
| July 3                     | 39                    | 39           | 16                    | 16           | 26                    | 26           | 14                     | 13           |
| 17                         | 43                    | 43           | 16                    | 16           | 29                    | 29           | 15                     | 14           |
| 31                         | 43                    | 43           | 18                    | 18           | 30                    | 30           | 14                     | 14           |
| Aug. 14                    | 44                    | 43           | 19                    | 19           | 31                    | 30           | 14                     | 13           |
| 28                         | 44                    | 43           | 17                    | 17           | 31                    | 30           | 16                     | 15           |
| Sept. 11                   | 44                    | 43           | 16                    | 17           | 29                    | 29           | 17                     | 16           |
| 25                         | 41                    | 40           | 14                    | 13           | 26                    | 26           | 16                     | 15           |
| Oct. 9                     | 38                    | 36           | 11                    | 10           | 24                    | 24           | 15                     | 15           |
| 23                         | 36                    | 35           | 10                    | 10           | 22                    | 22           | 14                     | 14           |
| Nov. 6                     | 34                    | 33           | 10                    | 10           | 23                    | 23           | 11                     | 11           |
| 20                         | 33                    | 32           | 13                    | 13           | 24                    | 24           | 9                      | 9            |
| Dec. 4                     | 32                    | 32           | 13                    | 13           | 22                    | 22           | 9                      | 9            |
| 18                         | 31                    | 30           | 11                    | 10           | 21                    | 21           | 10                     | 9            |
| <i>1917</i>                |                       |              |                       |              |                       |              |                        |              |
| Jan. 1                     | 32                    | 30           | 11                    | 10           | 21                    | 20           | 10                     | 9            |
| 15                         | 32                    | 29           | 11                    | 10           | 20                    | 20           | 10                     | 9            |
| 29                         | 31                    | 29           | 11                    | 10           | 20                    | 20           | 11                     | 10           |
| Feb. 12                    | 32                    | 30           | 7                     | 7            | 20                    | 19           | 12                     | 11           |
| 26                         | 32                    | 32           | 7                     | 7            | 20                    | 20           | 13                     | 12           |
| Mar. 12                    | 32                    | 32           | 7                     | 8            | 21                    | 22           | 11                     | 11           |

TABLE XIII.

*Data for each 4-week period of each of the two series, including: mean evaporating power of the air (the average daily loss from the standard white spherical atmometer), mean radiation (average daily difference between losses from black and from white sphere), and total duration of sunshine.*

| 4-week<br>period<br>ending | Evap. power<br>of air (av. daily loss<br>from st'd white sphere). |            | Radi-<br>ation (av. daily differ-<br>ence between loss from<br>black and white sphere). |            | Total dur-<br>ation of<br>sunshine |
|----------------------------|-------------------------------------------------------------------|------------|-----------------------------------------------------------------------------------------|------------|------------------------------------|
|                            | Exp.                                                              | Shelt.     | Exp.                                                                                    | Shelt.     |                                    |
| <i>1916</i>                | <i>cc.</i>                                                        | <i>cc.</i> | <i>cc.</i>                                                                              | <i>cc.</i> | <i>hrs.</i>                        |
| Mar. 13                    | 20.0                                                              | 14.1       | 2.03                                                                                    | .92        | 166                                |
| 27                         | 20.0                                                              | 14.3       | 2.34                                                                                    | .93        | 179                                |
| Apr. 10                    | 18.9                                                              | 13.6       | 2.50                                                                                    | .98        | 155                                |
| 24                         | 20.3                                                              | 15.2       | 3.27                                                                                    | 1.23       | 178                                |
| May 8                      | 21.2                                                              | 16.4       | 3.51                                                                                    | 1.15       | 224                                |
| 22                         | 18.2                                                              | 14.6       | 3.09                                                                                    | 1.01       | 241                                |
| June 5                     | 16.7                                                              | 13.9       | 3.33                                                                                    | 1.28       | 246                                |
| 19                         | 14.9                                                              | 12.4       | 3.36                                                                                    | 1.44       | 200                                |
| July 3                     | 15.6                                                              | 12.6       | 3.77                                                                                    | 1.55       | 222                                |
| 17                         | 18.0                                                              | 14.6       | 4.17                                                                                    | 1.63       | 269                                |
| 31                         | 16.9                                                              | 13.6       | 3.83                                                                                    | 1.13       | 229                                |
| Aug. 14                    | 17.1                                                              | 13.6       | 3.74                                                                                    | 1.43       | 202                                |
| 28                         | 19.2                                                              | 15.1       | 4.11                                                                                    | 1.46       | 262                                |
| Sept. 11                   | 18.6                                                              | 14.6       | 4.04                                                                                    | 1.35       | 279                                |
| 25                         | 15.0                                                              | 12.1       | 3.45                                                                                    | 1.44       | 249                                |
| Oct. 9                     | 11.8                                                              | 9.9        | 3.23                                                                                    | 1.51       | 233                                |
| 23                         | 11.0                                                              | 9.0        | 2.98                                                                                    | 1.30       | 206                                |
| Nov. 6                     | 15.1                                                              | 11.5       | 2.70                                                                                    | 1.46       | 210                                |
| 20                         | 17.8                                                              | 13.0       | 2.00                                                                                    | 1.33       | 197                                |
| Dec. 4                     | 16.1                                                              | 11.6       | 1.02                                                                                    | .61        | 159                                |
| 18                         | 16.5                                                              | 11.9       | .70                                                                                     | .25        | 158                                |
| <i>1917</i>                |                                                                   |            |                                                                                         |            |                                    |
| Jan. 1                     | 17.1                                                              | 12.1       | .65                                                                                     | .20        | 146                                |
| 15                         | 16.9                                                              | 11.9       | .76                                                                                     | .18        | 124                                |
| 29                         | 16.9                                                              | 12.1       | 1.15                                                                                    | .23        | 122                                |
| Feb. 12                    | 17.1                                                              | 12.4       | 1.58                                                                                    | .31        | 149                                |
| 26                         | 17.5                                                              | 12.6       | 1.81                                                                                    | .30        | 167                                |
| Mar. 12                    | 17.9                                                              | 12.8       | 1.91                                                                                    | .25        | 142                                |



TABLE XIV.

*Derived plant data for each 4-week period of each of the two series, including transpiration per gram of dry weight, transpiration per square centimeter of leaf area, total dry weight per square centimeter of leaf area, relative transpiring power (transpiration per cubic centimeter of water evaporated from the white spherical atmometer), and relative transpiring power per square centimeter of leaf area, all expressed as relative numbers for each period; the value of the first period of the exposed series is taken as unity in each case and the actual value is given in parenthesis below the value 1.00.*

| 4-week period ending | Trans. per gram dry weight (water requirement). |        | Trans. per sq. cm. of leaf area (one side). |        | Total dry wt. per sq. cm. of leaf area (one side). |        | Relative transpiring power (trans. divided by evap.). |        | Relative transpiring power per sq. cm. of leaf area (one side). |        |
|----------------------|-------------------------------------------------|--------|---------------------------------------------|--------|----------------------------------------------------|--------|-------------------------------------------------------|--------|-----------------------------------------------------------------|--------|
|                      | Exp.                                            | Shelt. | Exp.                                        | Shelt. | Exp.                                               | Shelt. | Exp.                                                  | Shelt. | Exp.                                                            | Shelt. |
| <i>1916</i>          |                                                 |        |                                             |        |                                                    |        |                                                       |        |                                                                 |        |
| Mar. 13              | 1.00<br>(.285<br>g.)                            | 1.01   | 1.00<br>(1.42<br>g.)                        | .82    | 1.00<br>(.0049<br>g.)                              | .82    | 1.00<br>(.344<br>g.)                                  | .76    | 1.00<br>(.0025<br>g.)                                           | 1.20   |
| 27                   | 1.03                                            | 1.09   | .99                                         | .90    | .98                                                | .84    | 1.26                                                  | .99    | 1.00                                                            | 1.28   |
| Apr. 10              | .99                                             | 1.03   | 1.15                                        | 1.06   | 1.18                                               | 1.04   | 1.47                                                  | 1.01   | 1.24                                                            | 1.56   |
| 24                   | 1.22                                            | 1.19   | 1.61                                        | 1.24   | 1.35                                               | 1.06   | 1.89                                                  | 1.45   | 1.60                                                            | 1.64   |
| May 8                | 1.11                                            | 1.19   | 1.62                                        | 1.38   | 1.49                                               | 1.18   | 1.84                                                  | 1.56   | 1.56                                                            | 1.72   |
| 22                   | 1.02                                            | 1.05   | 1.28                                        | 1.03   | 1.29                                               | 1.00   | 2.22                                                  | 1.62   | 1.44                                                            | 1.44   |
| June 5               | 1.04                                            | 1.08   | 1.28                                        | 1.18   | 1.25                                               | 1.12   | 2.25                                                  | 1.80   | 1.56                                                            | 1.72   |
| 19                   | .97                                             | 1.07   | 1.16                                        | .94    | 1.20                                               | .90    | 2.39                                                  | 1.94   | 1.56                                                            | 1.52   |
| July 3               | 1.04                                            | 1.14   | 1.21                                        | 1.09   | 1.18                                               | .98    | 2.45                                                  | 2.35   | 1.56                                                            | 1.76   |
| 17                   | 1.21                                            | 1.37   | 1.53                                        | 1.01   | 1.29                                               | .76    | 2.35                                                  | 2.18   | 1.72                                                            | 1.40   |
| 31                   | 1.14                                            | 1.39   | 1.43                                        | 1.29   | 1.27                                               | .94    | 2.44                                                  | 1.88   | 1.72                                                            | 1.92   |
| Aug. 14              | 1.27                                            | 1.54   | 1.58                                        | 1.40   | 1.27                                               | .92    | 2.41                                                  | 2.02   | 1.88                                                            | 2.08   |
| 28                   | 1.56                                            | 1.74   | 1.71                                        | 1.56   | 1.12                                               | .92    | 2.18                                                  | 1.44   | 1.80                                                            | 2.08   |
| Sept. 11             | a                                               | 1.55   | a                                           | 1.49   | a                                                  | .98    | a                                                     | 1.45   | a                                                               | 2.08   |
| 25                   | 1.18                                            | 1.30   | 1.60                                        | 1.28   | 1.39                                               | 1.00   | 2.35                                                  | 1.34   | 2.16                                                            | 2.16   |
| Oct. 9               | .97                                             | 1.12   | 1.15                                        | .96    | 1.20                                               | .88    | 1.78                                                  | 1.20   | 1.96                                                            | 1.96   |
| 23                   | 1.05                                            | 1.12   | 1.02                                        | .88    | 1.00                                               | .80    | 1.27                                                  | .82    | 1.88                                                            | 1.96   |
| Nov. 6               | 1.21                                            | 1.51   | 1.08                                        | 1.05   | .92                                                | .71    | 1.16                                                  | .72    | 1.44                                                            | 1.84   |
| 20                   | 1.31                                            | 1.51   | 1.15                                        | 1.05   | .90                                                | .71    | .71                                                   | .49    | 1.32                                                            | 1.64   |
| Dec. 4               | 1.06                                            | 1.24   | .86                                         | .76    | .82                                                | .63    | .56                                                   | .36    | 1.08                                                            | 1.32   |
| 18                   | 1.09                                            | 1.44   | .84                                         | .82    | .78                                                | .57    | .48                                                   | .32    | 1.04                                                            | 1.40   |
| <i>1917</i>          |                                                 |        |                                             |        |                                                    |        |                                                       |        |                                                                 |        |
| Jan. 1               | 1.01                                            | 1.16   | .68                                         | .66    | .69                                                | .57    | .40                                                   | .26    | .80                                                             | 1.12   |
| 15                   | 1.04                                            | 1.26   | .68                                         | .67    | .65                                                | .55    | .36                                                   | .20    | .80                                                             | 1.16   |
| 29                   | 1.26                                            | 1.45   | .70                                         | .80    | .57                                                | .57    | .25                                                   | .16    | .84                                                             | 1.36   |
| Feb. 12              | 1.17                                            | 1.35   | .78                                         | .77    | .67                                                | .57    | .29                                                   | .21    | .92                                                             | 1.28   |
| 26                   | 1.27                                            | 1.61   | .78                                         | .87    | .63                                                | .55    | .34                                                   | .19    | .92                                                             | 1.40   |
| Mar. 12              | 1.39                                            | 1.55   | 1.03                                        | .98    | .76                                                | .63    | .56                                                   | .28    | 1.16                                                            | 1.56   |

a Data not obtained because of insect injury to plants.

one of these particular growth criteria. Each value represents an average growth rate for a single plant for the designated 4-week period.

Table XII gives the maximum and minimum temperatures, average daily mean temperature and average daily temperature range, for each 4-week period of the exposed and sheltered series. The first two double columns give the actual maximum and minimum for each 4-week period. The last two double columns give the average daily mean and the average daily range respectively, these values being obtained by averaging the four weekly values representing each 4-week period.

Table XIII presents in the first double column the evaporating power of the air as the average water loss per day from the white spherical atmometer for each 4-week period. Radiation for each 4-week period as the average daily difference between the losses from the black and white components of the radio-atmometer, is given in the second double column of this table. The total duration of sunshine for each 4-week period is recorded in the last column.

Table XIV presents derived plant data for the 4-week periods. Each particular kind of data is expressed as numbers relative to the value of its first culture set in the *exposed* series (period ending March 13), and the actual value corresponding to 1.00 is given just below it in parenthesis. In this table appear values for transpiration per gram of dry weight (water requirement), transpiration per square centimeter of leaf area (one side), total dry weight produced per square centimeter of leaf area (one side), relative transpiring power (transpiration divided by water loss from white spherical atmometer), and relative transpiring power per square centimeter of leaf area (one side), for each set in each series.

*Monthly indices.* Table XV gives data showing approximate indices of the efficiency of the climatic complex in the unmodified greenhouse (exposed series) to favor the processes of stem elongation, dry weight increase, leaf-area increase and water loss by transpiration, for each *calendar month*. These indices are expressed as absolute values and also as values relative to the June value taken as unity for each particular kind of measurement.

Table XVI shows data representing the approximate monthly indices of radiation as measured by the average daily radio-atmometer difference, and of sunshine duration as the average daily value. Relative values, in terms of the corresponding value for the month of June are also given in each case.

TABLE XV.

*Data showing approximate indices of the efficiency of the climatic complex in the greenhouse (exposed series), to favor the processes of stem elongation, dry-weight increase, leaf-area increase and water loss by transpiration, for each calendar month; also the average leaf-area and dry-weight increase.*

| Month | Stem height |          | Total dry weight |          | Total leaf area |          | Transpirational water loss |          | Average of weight and area Relative |
|-------|-------------|----------|------------------|----------|-----------------|----------|----------------------------|----------|-------------------------------------|
|       | Absolute    | Relative | Absolute         | Relative | Absolute        | Relative | Absolute                   | Relative |                                     |
|       | <i>cm.</i>  |          | <i>grams</i>     |          | <i>sq. cm.</i>  |          | <i>grams</i>               |          |                                     |
| Jan.  | 31.5        | .64      | .168             | .13      | 43.3            | .20      | 46                         | .11      | .17                                 |
| Feb.  | 34.5        | .70      | .350             | .27      | 75.8            | .35      | 96                         | .24      | .31                                 |
| Mar.  | 50.8        | 1.03     | .794             | .61      | 135.4           | .63      | 254                        | .63      | .62                                 |
| Apr.  | 64.1        | 1.30     | 1.158            | .90      | 178.7           | .84      | 350                        | .87      | .87                                 |
| May   | 66.1        | 1.34     | 1.292            | 1.00     | 203.1           | .95      | 389                        | .96      | .98                                 |
| June  | 49.3        | 1.00     | 1.292            | 1.00     | 213.9           | 1.00     | 404                        | 1.00     | 1.00                                |
| July  | 64.1        | 1.30     | 1.218            | .94      | 194.9           | .91      | 406                        | 1.00     | .93                                 |
| Aug.  | 72.0        | 1.46     | 1.050            | .81      | 167.8           | .79      | 385                        | .95      | .80                                 |
| Sept. | 69.0        | 1.40     | .787             | .61      | 135.4           | .63      | 277                        | .69      | .62                                 |
| Oct.  | 56.2        | 1.14     | .505             | .39      | 105.6           | .49      | 162                        | .40      | .44                                 |
| Nov.  | 45.3        | .92      | .289             | .22      | 78.5            | .37      | 96                         | .24      | .30                                 |
| Dec.  | 37.5        | .76      | .188             | .15      | 58.2            | .27      | 62                         | .15      | .21                                 |

TABLE XVI.

*Data showing approximately monthly indices of radiation (as measured by the average daily radio-actinometer difference), and of sunshine duration (as the average daily value).*

|       | Radiation. (av. daily difference between loss from black and from white sphere) |          | Duration of sunshine. (av. daily). |          |
|-------|---------------------------------------------------------------------------------|----------|------------------------------------|----------|
|       | Absolute                                                                        | Relative | Absolute                           | Relative |
|       | <i>grams</i>                                                                    |          | <i>hours</i>                       |          |
| Jan.  | 1.18                                                                            | .30      | 4.6                                | .54      |
| Feb.  | 1.87                                                                            | .48      | 5.5                                | .64      |
| Mar.  | 2.40                                                                            | .62      | 5.9                                | .69      |
| Apr.  | 3.05                                                                            | .78      | 6.9                                | .81      |
| May   | 3.53                                                                            | .91      | 7.8                                | .92      |
| June  | 3.90                                                                            | 1.00     | 8.5                                | 1.00     |
| July  | 4.04                                                                            | 1.04     | 9.0                                | 1.05     |
| Aug.  | 3.98                                                                            | 1.02     | 8.9                                | 1.04     |
| Sept. | 3.61                                                                            | .93      | 8.5                                | 1.00     |
| Oct.  | 2.74                                                                            | .70      | 7.6                                | .89      |
| Nov.  | 1.34                                                                            | .34      | 6.4                                | .75      |
| Dec.  | .65                                                                             | .13      | 5.0                                | .59      |

THE SEASONAL MARCH OF THE GREENHOUSE CLIMATE  
AS MEASURED BY THE GROWTH OF THE PLANTS

## INTRODUCTION

Although a considerable number of observations and of data deduced therefrom are available for shorter periods than those of four weeks, only the latter will now be considered. The overlapping of the periods furnishes twice as much detail of the annual march of each environmental efficiency value as would have been the case if the 4-week periods had simply been consecutive. The integrated index values for each of the various plant process rates for these periods represent time intervals of four weeks. If a graph be drawn to represent the fluctuations that occurred in one of these values throughout the year, letting the abscissas represent time from the beginning of the entire series and making the ordinates proportional to the various plant process rate values, known points (ordinate values) on this graph will occur at time intervals of two weeks. Each 4-week value is plotted for the time interval that it represents, and, since a new 4-week period began every two weeks, these points fall at two-week intervals measured on the axis of abscissas.

Following in a general way the suggestion of Livingston and McLean care was taken to have the plants at the beginning of one exposure period as nearly as possible like those at the beginning of all other exposure periods. The seed phase was not used as the starting-point in these exposures, but young seedlings of very nearly the same size were always used. From the viewpoint of the Livingston-McLean suggestion, the zero-point of the plants (considering them as instruments for the measurement of environmental complexes) is taken as that stage of growth represented by the buckwheat seedlings when placed in the culture jars. The assumption is made, as far as the purposes of this study are concerned, that the internal conditions of all seedlings thus used throughout the year were the same. After being placed in the culture jars they were always exposed for 4 weeks to the conditions that were to be measured, and differences between the amount of growth (or other plant process) for one period and that for another are considered as due to differences in the environmental complexes for the corresponding periods, as these environmental complexes affected the plants. Thus, the 4-week plant values given in the tables are taken as indices of the various degrees of effectiveness of the environmental complexes for the different exposure periods. The graph of plant growth rates mentioned above is thus seen to be a graph of the effectiveness of the surroundings to produce a 4-week increment of growth in these standard buckwheat seedlings. Since the power of the surroundings to produce growth (or to bring about any other process of plant activity) can be measured in as many ways as plant activities can be measured,



there are of course as many indices of environmental effectiveness as there are kinds of 4-week data. Of the various kinds of plant data given in the tables, only those of height, leaf area, dry weight and transpirational water loss (which may also be taken as an approximate measure of water absorption) will be considered in this paper.

In order to study the conditions of the aerial environment of a standard plant as these conditions vary in intensity throughout the year, it is desirable to remove or standardize all other environmental conditions that may exert significant influence on the plant. This may be accomplished by following the same general method as is used to avoid complications brought about by initial internal conditions of the plant. The entire non-aerial complex influencing the buckwheat plants in this experiment was that surrounding the roots and was represented by the mass of nutrient solution contained in the culture jar. These solutions were always chemically and osmotically alike at the beginning of each 4-week exposure period and at the beginning of the second 2-week portion of this same period, but changes of course took place in the culture solutions during these 2-week periods and there is no doubt that the manner and rate of change was different for each period. No attempt was made to prevent such differences and they received no attention in this study, because of the additional labor that their study would have involved. One precaution was taken, nevertheless. Whenever transpiration rates were high enough to lower the solution level to any marked extent, water was added during the last week of the 4-week exposure period, to prevent the root systems from becoming unduly exposed to the air and too free from the solution. No attempt was made to control or take into account the temperature fluctuations of the solutions but it is assumed that these temperatures were practically the same as the air temperatures, with a slightly greater lag. It may be considered that all unknown changes that occurred in the root environment were indirect effects of preceding changes in the aerial environment.

For the purposes of this study it may be considered that the effectiveness of the chemical surroundings of the plant roots varied in about the same way for all the different 4-week periods, that the water-supplying power of the root surroundings was always so great as to introduce no special limitation on growth, and that the internal conditions of the plants were the same at the beginning of all the 4-week periods. It is also assumed, for present purposes, that the chemical conditions of the aerial surroundings of the plants were always effectively the same throughout the year; that the atmosphere of the greenhouse always had physiologically the same carbon-dioxide and oxygen content, and that it was always

free from poisonous gases. Considering these environmental complexes constant and letting the solution temperatures be directly dependent on air temperatures and included therein, it follows that observed differences in the plant process rates, from period to period, may be regarded as causally related to differences in the aerial complexes for these same periods.

The present section deals with various 4-week plant values taken as indices of the physiological efficiency or power of the aerial physical environment, as this efficiency altered from period to period. By the aerial environment is here meant the climatic complex, as the adjective *climatic* is usually interpreted, composed of air temperature, atmospheric evaporating power, and radiation. The following paragraphs therefore describe the annual march of the plant-producing power of the climatic complex of this particular greenhouse for the 13 months covered by this study. The climatic conditions are described in terms of the 4-week rates of stem-height increase, leaf-area increase, dry-weight production and transpirational water loss. Each index value represents the effect on a single average buckwheat plant for a time period of 4 weeks. In this discussion, as has been done before, the various periods will be designated by their respective dates of ending, and the yearly graphs show each index value plotted at the *end* of the 4-week period for which it stands. These index values are expressed in terms relative to the corresponding index for the period ending March 13, 1916, of the exposed series, which is taken as unity in each case.

Since greenhouse cultures are frequently shaded in various ways, especially during the summer months, the sheltered series, already mentioned, was introduced. The indices from this series will be considered to some extent in the present section and will also be employed in the last section of the paper.

#### SEASONAL MARCH OF THE PLANT VALUES

##### *Relative Values and their Graphs*

*Unmodified plant graphs.* The relative values given in table XI represent the average rates of stem height, dry weight and leaf area production and transpirational water loss for each 4-week exposure period. They furnish quantitative data for a comparative study of the influence exerted upon the plants by the various complexes of the climatic conditions prevailing in this greenhouse during the consecutive 13 months of the study. These data, which are the indices of plant process rates, vary from period to period in the same series and they also differ for corresponding periods in the two series.

These eight series of relative numbers are represented graphically in figure 4. The ordinates of these four pairs of graphs are the

plant values and the abscissas represent the time of year. Data from the exposed cultures are indicated by full lines and those from the sheltered cultures by dash lines. Dotted lines are smoothed graphs. All the graphs are drawn to the same scale.



FIG. 4.—Graphs of height, dry weight, leaf area and transpiration plotted from the four-week relative values. Data from the exposed cultures are indicated by full lines and those from the sheltered cultures by dash lines. The dotted lines are smoothed graphs.

In studying these and the other graphs that follow, as well as in studying the 4-week values given in the tables, it is to be remembered that each of these values represents the entire 4-week period

and that consecutive values represent overlapping periods. On this account the apparent dates of occurrence of minima, maxima, etc., are not to be taken as definite; it is quite possible that a low point representing a certain period on one graph may correspond to a similar low or high point for the next earlier or later period on another graph. Exact correspondence among the various plant and instrumental graphs is not to be expected.

A general inspection of the four graphs representing the exposed series shows that each has a region of maximal values for the summer and one of low values for the winter. For the spring period there is generally an upward slope and for the autumn period the slope is downward in each case. Numerous irregularities appear, as would be expected in graphs showing the annual march of climatic conditions. It is safe to suppose that graphs of these kinds for any other single year would have the same general form, but would show irregularities more or less different from those of this year. Following climatological experiences, it may also be supposed that graphs representing the means of the corresponding values for a large number of years would become smooth if a sufficient number of years were represented. Furthermore, the forms of such a set of average or normal graphs should not depart very greatly from the general forms obtained by artificially smoothing out the irregularities of the graphs in figure 4.

Before considering the smoothed graphs thus suggested, it should be noted that the irregularities are but slight in those portions representing periods of low values and that they are greatest in portions representing late spring, summer and early autumn. The exceptionally high value found on all four graphs for the period ending November 6, is probably due to the beginning of the application of artificial heat in the greenhouse. It will also be observed that the graph for the index of stem-height production is peculiar in respect to a very low secondary minimum value for the period ending July 3, and that this low region in the graph also includes the values for the preceding and following periods.

The peculiarity just mentioned as characteristic of the height graph represents by far the most pronounced irregularity in any of these plant graphs, and this fact, together with its occurrence about the date of the summer solstice, suggests that it should not be regarded as pertaining especially to this particular summer. It is possible that this period of low rates of stem elongation in these buckwheat plants growing in an unshaded greenhouse may represent a period when the well-known retarding effect of light on this process of growth in height is near its maximum for the year. Another secondary minimum value occurs for the period ending August 28, but this depression is comparatively slight and there is no reason for supposing it to be other than one peculiar to this



particular year. Both of these considerations were taken into account in smoothing the height graph. In the last section of this paper a more detailed discussion will be devoted to the height values and their graphs.

Inspection of the relative plant values given in the tables, or in the graphs of figure 4, makes it apparent that the whole study began shortly after these values had begun to increase in the spring of 1916, and that the observations were discontinued shortly after the beginning of a similar increase in the spring of 1917. The values for the period ending March 13, 1916, however, are not numerically the same as the corresponding ones for the period ending March 12, 1917; in every case the later values are lower. If the vitality (initial internal conditions) of the seeds is considered to have remained the same throughout the year, the lower spring values of 1917 appear to indicate that the spring of that year was "later" than that of the preceding one. There was no noticeable depreciation in the germinating power of the seeds for any exposure period, and there is no reason to suspect that the winter values of 1915-16 or the summer values of 1917, had these values been obtained, would have been markedly different from the winter and summer values, respectively, of the series here recorded. It is clear that the first and last values of a normal annual graph, if this were obtained by many years' repetition, should be equal for each kind of measurement. To make the smoothed graphs conform to this principle, their terminal portions have been somewhat arbitrarily modified, the common index of the two years being taken as the average of the two observed values. In the absence of data covering several years, this method of smoothing was employed to construct the tentative normal graphs, which are represented by the dotted lines of figure 4.

*Smoothed plant graphs.* The smoothed plant graphs of stem-height, dry-weight and leaf-area production and of transpirational water loss for the exposed series of cultures (dotted lines, fig. 4) may be regarded as tentative normal graphs of the climatic conditions of the greenhouse employed, as these conditions affect the respective plant processes. Furthermore, the ordinate values of these smoothed graphs may be taken to represent the approximate process rates that may be expected whenever this kind of plant is grown in the general way here followed, under greenhouse conditions similar to the ones that prevailed in this study. However, it is not to be forgotten that, since, different years are known to differ considerably both in the times of occurrence and in the actual values of their climatic maxima and minima, these tentative normal graphs may differ considerably from actual normals that might be constructed from averages of many years' observations. The smoothed graph always shows its beginning as definitely below the actual ordinate value for 1916, and above that for 1917, and it may be that the true

normal would conform more nearly to either one or the other of the two actual end values than to the average value used for the smoothed graph. The true normal graph for any criterion might be higher or lower, in certain regions or throughout, than the tentative normal as shown in figure 4. The merely tentative feature of these smoothed graphs needs to be emphasized whenever deductions are to be made from them.

Since climatic data are frequently averaged by calendar months and appear thus in many climatological publications, the average monthly values have been read from the smoothed graphs of figure 4 and these are shown in table XV. These derived values are simply the magnitudes of the ordinates of the smoothed graph which correspond to the middles of the respective calendar months. Since only an approximation is sought in each case, no account has been taken of the fact that the graphs themselves are based on a method of plotting which gives to each actual point the abscissa value corresponding to the end of the corresponding 4-week period rather than to the middle of that period.

It must be remembered when employing either these index values or the graphs themselves, for estimating the climatic efficiency of a particular time of year or for predicting the average rate of a plant process for a given month, that they refer to Japanese buckwheat, grown in a particular nutrient solution under the conditions existing in this study, and also that the climatic complexes are surely not always the same from year to year, but vary more or less on either side of the normal or mean. It is also important to emphasize that data from which the graphs of figure 4 were prepared refer to 4-week growth periods.

Attention may be called to the maximum and minimum values of these four plant indices, with the periods of their occurrence, as shown by the smoothed graphs. As has been mentioned before, the stem-height graph exhibits two maximal regions, one occurring for the period ending May 15, the other for that ending August 28. The first has an absolute value of 67.0 and the second 72.0 cm. (The absolute values employed in these references are obtained by multiplying the relative value found on the smoothed graph by the absolute value that was taken as unity; see table XI for these.) Between the two maxima occurs the summer minimum of 48.8 cm., for the 4-week period ending July 3. The winter minimum of 31.1 cm. occurs for the period ending February 12. The extent to which the summer minimum approaches the winter minimum is quite remarkable. The highest value is about twice as great as the lowest, which gives some idea of the annual range in the stem height production. The maximum rate of dry weight increase is 1.306 g. for the 4-week period ending June 19, and the minimum of .162 g. occurs for the period ending January 15; the highest value was

about 8 times as great as the lowest. For the rate of increase in leaf area the maximum, 211.2 sq. cm., occurs for the 4-week period ending July 3, and the minimum, 43.3 sq. cm., occurs for the period ending January 29; the greatest value is about 5 times the smallest. The range of the rate of transpirational water loss extends from the maximum, 406.0 g., to the minimum, 46.2 g., for the 4-week periods ending July 17 and January 29, respectively; the highest rate is approximately 9 times the lowest.

Considering the index values for the months of the calendar year, as shown in table XV, the two maxima rates of stem elongation are for May and for August, and the minimum is for January. Dry weight production is greatest for May and June and least for January. The increase in leaf area shows its highest rate for June and its lowest for January. The rate of transpiration is represented as highest for June and July and lowest for January. The least suitable month of the year for all four of these plant processes is January. Although the most suitable season is not indicated as exactly the same for all the processes referred to, late spring, summer and early autumn are to be regarded as very good seasons in all cases, excepting that a period of several weeks before and after the summer solstice is shown as poorly suited for growth in height.

#### *Derived Plant Data.*

*Weight-area index.* Since the graphs of weight and area have similar form it appeared worth while to average these two values for each period, thus obtaining a new kind of plant value that may be termed the weight-area index. This amounts to carrying the smoothing process somewhat further than was done in preparing the smoothed graphs of these separate plant features. The graph of the averages of these relative values is presented in figure 5. Of course this composite graph is very similar in form to the graphs of its component indices.

Other derived plant indices, all of which have been hitherto employed in physiological studies, are the three ratio values: (1) transpirational water-loss per unit of dry weight, (2) transpirational water-loss per unit of leaf area, and (3) dry weight per unit of leaf area. The first of these values has been called the *water requirement*<sup>11</sup> of the plant. The second may be designated as the *areal coefficient of transpiration* (either assuming that cauline and petiolar transpiration are proportional to the total area of the leaf blades, or entirely neglecting these two relatively unimportant components of the total transpiration). The third derived plant value, the average amount of dry material produced per unit of leaf area, may be termed the *areal coefficient of dry-weight increase*.

11.—For literature on the water requirement of plants see: Briggs, L. J., and Shantz, H. L. The water requirement of plants. 11. A review of the literature. U. S. Dept. Agric., Bur. Plant Ind. Bull. 285. 1913.  
Kieselerbach, T. A. Transpiration as a factor in crop production. Nebraska Agric. Exp. St. Research Bull. 6. 1916.

These three derived plant values are given in table XIV for the 4-week periods, and the graphs of these indices of the exposed series are shown in figure 5.

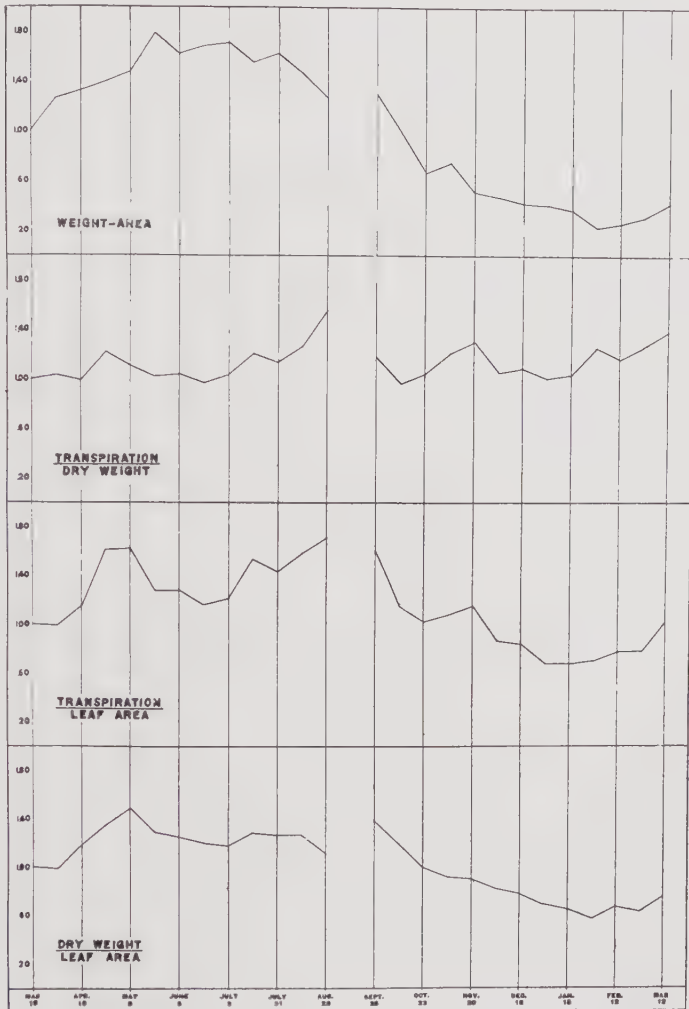


FIG. 5.—Graphs of weight-area average, transpiration per unit of dry weight (water requirement), transpiration per unit of the leaf area and dry weight per unit of leaf area, all plotted from the four-week relative values of the exposed cultures.

*Water requirement.* Briggs and Shantz<sup>12</sup> have called attention to the fact that different climatic complexes may be compared in

12—See footnote 10, especially page 82 of the reference.



terms of the different water requirements of the same kind of plants grown to maturity under different sets of climatic conditions. At Akron, Colorado, these writers found the water requirement of buckwheat to be 578 for the summer of 1913. Hellriegel found this value to be 371 at Dahme, Germany, in 1883, and Wollny found it to be 646, at Munich, in 1876. These determinations were made with plants rooted in soil and fully exposed to the air. The greenhouse-grown solution cultures of the present study showed the highest value of the water requirement to be 445 for the period ending August 28, and the lowest to be 275 for the period ending October 9. Other similarly low values were obtained for the periods ending April 10 and June 19.

A general survey of the graph of water requirement fails to suggest any general relation between the magnitude of this index and the climatic seasons. The variations are seen to be irregular and it is suggested that a normal graph (one derived from many years of observation) might have the form of a horizontal line. This is also suggested by the general similarity in form between the smoothed graphs of transpiration and of dry weight increase (fig. 4). If the detailed variations appearing in the water-requirement graph (fig. 5) are compared with the corresponding ones shown by the graph of the evaporating power of the air (fig. 6), which will be considered below, it is strongly suggested that the water-requirement fluctuations may be somewhat closely related to variations in the intensity of evaporation. Such a relation might be expected from the nature of the water requirement. It is also suggested that the variations in water requirement may be related to those in the index of daily mean temperatures as shown by the graph of this 4-week index in figure 6. These water-requirement fluctuations may be expected to change with the character of the prevailing climatic complex as this varies from year to year.

If the normal water requirement graph be considered as a horizontal line it follows that the rate of transpiration may be regarded as proportional to the rate of dry weight increase for the same period. Following this supposition, an approximate constant of proportionality for the exposed series of buckwheat plants may be obtained by averaging the water-requirement values of the exposed series for the year; this average is 325. Multiplying the average transpiration for each set by this constant gives a value that rather closely approximates the corresponding total dry weight value.

*Areal coefficient of transpiration.* The graph of the ratio of transpiration to rate of increase in leaf area (fig. 5) resembles that of water requirement in some respects, but a seasonal march is strongly indicated, with low winter values and high summer values. There is a marked depression in the graph for the region shown between the periods ending May 22 and July 3. As is true in the case of the water-

requirement graph, many of the irregularities appear to be related in some respects to those of the evaporation graph (fig. 6). Furthermore, some of the irregularities seem to be related to those of the radiation graph (fig. 6). The maximum value of this derived index is 243, occurring for the period ending August 28, and the minimum value is 96, for the period ending January 15; the maximum is about 2.5 times the minimum, and the average value for the whole year is 163. It appears that the extent of leaf area necessary for a given transpiration rate was much greater in summer than in winter, which seems to indicate (since no marked annual march is suggested for the evaporating power of the air fig. 6) that leaves produced in winter possessed a markedly higher transpiring power per unit of area than did summer leaves. This, together with the partial return toward the winter characteristics that is indicated for a period before and after the summer solstice, are the most interesting features of this derived value.

*Areal coefficient of dry weight increase.* The graph of the areal coefficient of dry weight shown in figure 5, indicates an annual march, with high values in summer and low ones in winter, in approximately the same regions as those in which high and low values occur for the areal transpiration coefficient, but the irregularities are less marked here. These irregularities seem to be related to variations in the climatic complex as some of these are indicated in the instrumental graphs (fig. 6). The maximum value of this coefficient is .0073 for the period ending May 8 and the minimum is .0028 for the period ending January 29; the yearly mean is .0051, and the maximum is about 2.6 times the minimum. The secondary low region for early summer is not clearly indicated on this graph and may be neglected. It seems that the amount of dry weight produced for a given area of leaves was more than twice as great for summer as for winter. This is not to be considered as the result of internal differences between summer and winter foliage, however, for the radiation index value (fig. 6) was much greater in summer. If it be supposed that the summer areal coefficient of dry weight was twice the winter coefficient, and also that the foliar photosynthetic power per unit of leaf area remained sensibly the same throughout the year, then it would appear that solar radiation was twice as effective to produce dry weight in summer as it was in winter. As will be noted below, the radio-atmometric index of radiation was 6 times as great for summer as for winter. Since the areal coefficient of dry weight, and the suppositions stated above, require only that effective radiation be twice as great for summer as for winter, it might be suggested that the radio-atmometer was something like 3 ( $6 \div 2$ ) times as sensitive to differences in radiation as were the plants, by the criterion here being considered. This is merely a suggestion, but it probably deserves emphasis that the radio-atmometer is much more sensitive to changes in total radiation

intensity than is any plant when considered as a photosynthesizing apparatus. Of course it is clear that most of the radiation absorbed by plant foliage goes to accelerate transpiration and that only a very little of it is effective to accelerate dry-weight production per areal unit of leaves.

### *Plant Values for the Sheltered Series.*

The values obtained from the plants grown in the cheese-cloth shelter are of interest mainly because they furnish information on the growth processes as these occurred under a very different climatic complex from that experienced by the exposed series. They are also useful in connection with the interpretation of the relations existing between the plant data and the instrumental data for the unshaded greenhouse. The conditions to which these plants were exposed do not correspond closely to those generally employed for greenhouse cultures in winter, but they may be regarded as essentially similar to the modified greenhouse conditions produced by heavy shades. While such shades are of course not usually employed for greenhouses in winter, they are very commonly used in summer, and the summer climatic conditions of the sheltered series of the present study were probably much more like the usual summer conditions of greenhouses in temperate regions than were the conditions of the exposed series for the summer months. On the other hand, the exposed series of this study had winter climatic conditions that corresponded to the winter climate commonly encountered in such greenhouses for the winter months. The cheese-cloth walls and top of the chamber probably made the shelter conditions somewhat more markedly different, in some respects, from those of the unshaded greenhouse than is usually the case where heavy shade is applied to the greenhouse as a whole, but it is safe to suppose that the direct effect of the cheese-cloth shade (in modifying the solar radiation to which the plants were exposed) was not as marked as would have been the case if the greenhouse had been as heavily shaded as is common when shade-plants are under cultivation in the temperate summer. Shades much more opaque than cheese-cloth are very frequently employed in such cases. Aside from these considerations, it is of course desirable, from the viewpoint of physiological science, to know what may be expected from such a plant as buckwheat when it is subjected to such modified conditions as were supplied by the cheese-cloth shelter in these studies. The brief discussion of the plant values from the sheltered series, as given below, which may be followed by referring to the graphs of figure 4, is intended merely to bring out some of the most outstanding features of this series. The derived plant values for the sheltered series will not be discussed.

In general, the climatic efficiency of the shelter chamber proved to be lower than that of the unsheltered greenhouse, by all four

plant criteria. The effect of the shelter was by no means so pronounced in the case of stem elongation as in the other three cases, however; the presence of the shelter seemed to prevent the occurrence of the exceptionally low rates of stem elongation that were shown by the exposed series for the early summer periods. It is to be observed that the graph for height (fig. 4) shows two points (corresponding to the 4-week periods ending July 3 and 17) that are notably higher for the sheltered than for the exposed series. In all other cases (excepting a single point on the graph for leaf area, which seems to be unrelated to any known conditions) the values from the sheltered series are either about equal to or considerably below the corresponding values from the exposed series. In short, the only instance of the shade being notably beneficial, with regard to these 4 growth criteria occurred for the period about the summer solstice. On the whole, however, the shelter exerted comparatively little influence on height growth for any season of the year.

While the difference between the sheltered and exposed series, as regards the 4-week rates of dry-weight and leaf-area production and of transpiration, is shown to have been much greater for summer than for winter, the *percentage* of decrease brought about by the shelter was much greater for mid-winter than for summer. Aside from the single exception noted for areal increase, the shelter did relatively more harm to plant growth, as measured by dry weight and leaf area production and by transpiration, in the winter than in the summer. It is especially interesting to note that, aside from the exception, all three rates for the plants within the shelter were very much retarded at all seasons, as compared with those shown for the exposed series.

### *General Conclusions from the Plant Values*

As so far considered, a general survey of the graphs shown in figure 4 brings out the fact that the unmodified conditions of the greenhouse were most favorable to the general growth of these buckwheat plants during two portions of the year, one extending from about the middle of April to about the middle of May, the other from early July to the middle of September. The limits just mentioned are only approximate, for there are slight differences in the times of beginning and in the lengths of these periods, according to the particular growth criterion used. The graphs for height and transpiration agree in showing relatively low values for a period occurring about the time of the summer solstice, and a similar feature is at least suggested by the graph for weight. This early summer period seems to have been less favorable than the one immediate preceding and the one immediately following, according to the criteria of height and transpiration.



The graphs of figure 4, as well as those of figure 5, further show that the winter season was particularly unfavorable to the general growth of these plants. The low plant values extend from early November to the latter part of March, or they approximately cover that portion of the year requiring artificial greenhouse heat. Whether or not the application of more artificial heat to the greenhouse might have greatly improved the growth of these plants for the winter months, is of course uncertain, but it seems probable that something more than temperature control is needed to bring about growth processes in winter that even approach those of summer.

These general conclusions are doubtless qualitatively familiar to everyone who has grown greenhouse plants throughout the year in temperate regions. The inadequacy of the winter climatic complex to favor a maximum or even a satisfactory rate of growth is well worth emphasizing and it is of greatest importance to experimenters in plant physiology, especially since such a large portion of the more refined experimentation of this science is done in college and university laboratories in which work is too frequently carried on only during the usual academic year, from September to June. Workers in other laboratories where plants are studied, while not usually limited to this portion of the year for their experimentation, are often constrained to limit their attention to the immediate needs of agricultural practice, so that both time and funds are lacking for satisfactory research in plant physiology. This science has thus been built up mainly by investigators working in colleges and universities, and our present knowledge of plant nutrition, metabolism, growth and development, is based to a very large extent on studies that may have been satisfactory enough as far as methods and apparatus are concerned, but that have been largely performed at a time of the year when the environmental conditions were not by any means the most favorable for plant activities. It appears that the most refined portions of this science have been built up, to a large extent, from studies on the physiology of generally unhealthy and stunted plants.

It is to be noted that the period of most courses of laboratory instruction in plant physiology includes only about two months, (in the late spring) when the climatic conditions are even fairly suitable to plant growth, if the results of this study are taken to be of general significance. The elementary student usually makes the acquaintance of many plants under conditions that favor anything but optimal or maximal process rates. Of course this state of affairs is appreciated in many educational institutions, where the experimentation involving healthy plants is frequently crowded into the last two or three months of the academic year, but the portion of this spring period that is best suited to plant growth is frequently unfavorable to the work of students and instructors because of the approaching end of the academic session. How instruction may be

improved in this regard deserves the attention of instructors in plant physiology and in all sciences that have to do with growing plants.

The results of McLean's investigations and those of the present study suggest a method for approximately describing climatic complexes for definite time periods in the same or in different localities, in terms of the abilities of such complexes to bring about growth processes in standard plants. For example, the climatic complex of this greenhouse for the 4-week period ending November 20 is described by its ability to produce, in these standard buckwheat plants, growth processes which may be expressed as a stem height of 51.7 cm., a dry weight of .327 g., a leaf area (one side) of 75.0 sq. cm., and a transpirational water loss of 122.1 g. Likewise, the climatic complex for this same 4-week period may be described in terms of instrumental measurements such as temperature, light intensity and atmospheric evaporating power, but at present it is impossible to integrate these instrumental measurements so as to describe the complex in terms of its value in producing plant growth. By employing a standard plant in some such way as was done in these studies the climatic efficiency for any period is directly expressed in terms of plant process rates for the plant. In this respect such a description is preferable to the instrumental one when efficiency for plant growth rather than for affecting physical instruments is the thing to be studied.

An objection, which may seem serious at first, to this method of employing a standard plant as an integrating instrument for measuring climatic environmental efficiencies, is that the process rates of the standard plant are not to be considered as directly applicable to other plants. An environmental complex that is excellent for buckwheat growth may not be good for the growth of wheat or potatoes, and the interpretation of buckwheat readings for wheat growth must be based on special experimental work showing the relations between the two kinds of organism. The same sort of special experimentation is necessary, however, if it be desired to interpret the readings of a group of instruments as showing climatic efficiency for the growth of wheat. Since no single instrument can be expected to integrate all the conditions that affect the plant, several instruments must necessarily be employed and the desired interpretation becomes exceedingly difficult. It seems probable that there may be greater similarity between the responses of different plants to the same set of conditions than there is between the responses of a plant and those of a group of instruments. Further experimentation is of course needed to determine what kinds of plant should be used as standards in such studies. McLean employed soybean and buckwheat was used in the present study but these two plants have not thus far been employed simultaneously, and perhaps other forms may be better than either of these.

# THE SEASONAL MARCH OF THE GREENHOUSE CLIMATE AS MEASURED BY PHYSICAL INSTRUMENTS AND THE CORRELATION OF INSTRUMENTAL WITH PLANT DATA

## GRAPHS OF THE INSTRUMENTAL VALUES

Relative values for the evaporating power of the air, radiation, daily mean temperature and daily temperature range were calculated

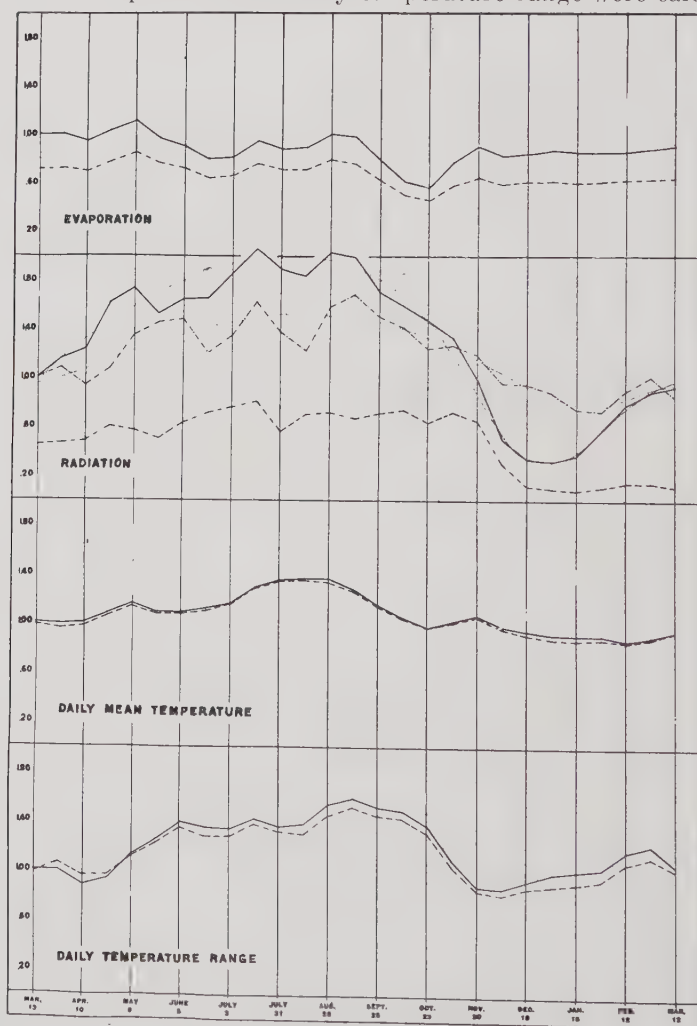


FIG. 6.—Graphs of evaporation (evaporation power of the air), radiation, average daily mean temperature and average daily range of temperature, all plotted from the four-week relative values. Data from the exposed series are indicated by full lines, those from the sheltered series by dash lines and those of sunshine by the dash-dot line. The dotted lines are smoothed graphs.

for each 4-week period for the exposed and sheltered series, and their graphs are presented in figure 6. Graphs of relative sunshine-duration values are also presented in this figure. These relative values are not given in the tables, but were obtained from summations of the daily values for the 4-week periods. The corresponding actual average values are presented in tables XII and XIII. The graphs of figure 6 are plotted in the same general way as are the corresponding plant graphs of figure 4. The following sections deal with these four graphs for the exposed series, after which those for the sheltered series will receive some attention. The instrumental graphs of figure 6 are to be compared with the plant graphs of figures 4 and 5.

### *Evaporating Power of the Air*

Inspection of the graph representing the evaporating power of the air shows that the portion representing the late autumn, winter and early spring is much less irregular than the rest. From the 4-week period ending November 6 to that ending June 5 this index shows rather uniform, high values (for the winter months the daily rate was about 18 cc. per day from the standard white sphere). The summer periods ending June 5 to July 3 show relatively low values; later summer periods, till that ending September 25, show values that equal or exceed the winter ones; and the lowest values for the year occurred for the periods ending October 16 and 23. The lowest atmometric index represents a daily average of 11 cc. for the 4-week period ending October 23. The highest value occurs for the 4-week period ending May 8, when the evaporation rate averaged 21.2 cc. per day. During the winter period (of artificial heat) the air of a greenhouse is of course warmer than the outdoor air, so that its saturation deficit<sup>13</sup> is generally high. The low evaporation periods correspond to times of high humidity of the outside air.

A comparison of the graph of evaporation with the other graphs brings out the fact that the late summer period of high evaporation rates corresponds to high temperature and radiation values and also to relatively low rates of dry-weight and leaf-area increase, but to relatively *high* rates of transpiration, as would be expected. A comparatively low point in the graph for evaporation occurs for the period ending June 19, and the graph of transpiration shows its most pronounced irregularity as very low values about the summer solstice. The smoothed transpiration graph has been drawn so as to neglect this feature entirely, but it is worthy of note. It is also interesting to note that the winter period of relatively high evaporation rates is also characterized by low plant growth rates, but it is not shown that these two facts are directly related.

<sup>13</sup>—Livingston, B. E. The vapor tension deficit as an index of the moisture condition of the air. Johns Hopkins Univ. Cir. March, 1917, p. 170-175.

Johnston, Earl S. Evaporation compared with vapor-pressure deficit and wind velocity. Mo. Weather Rev. 47: 30-33. 1919.



### *Radiation*

*Radiation in terms of radio-atmometric units.* A general survey of the radio-atmometric graph (full line, fig. 6) shows a very well-defined maximal region and an equally clear minimal one. The slope toward the winter minimum is steeper than the one from this minimum toward the summer maximum. The maximum value (an average difference of 4.17 cc. per day between the evaporation from the black and the white components of the radio-atmometer) occurs for the 4-week period ending July 17, while the periods ending August 28 and September 11 gave similar average daily values (4.11 and 4.04 cc. respectively). The lowest value (.65 cc.) occurs for the 4-week period ending January 1, while the period immediately preceding and the one immediately following gave similar low values (.70 and .76 cc., respectively). The highest value is approximately 6 times as great as the lowest.

Because of its slight irregularities, the smoothed radio-atmometric graph (dotted line on the full line graph, fig. 6) may be considered as reasonably approaching a normal graph. The part of the smoothed graph that is concave upward extends from about the period ending March 20 to about the period ending January 29, approximately 10 weeks in all. For the remainder of the year (about 42 weeks) the curve is convex upward. The maximal region of this smoothed graph extends over a period of approximately two months (July and August) and represents an average daily value of 4.00 cc. The minimum (about .65 cc.) occurs for the period ending January 1 and appears to correspond to the occurrence of the winter solstice. The apparent date of the summer maximum does not agree so well with that of the summer solstice; it occurs from four to six weeks after the solstice. Whether the graph here considered represents the march of the radio-atmometric index for the out-of-doors is not known, and the feature just mentioned is possibly related to the influence of the greenhouse glass. The smoothed graph of sunshine duration (dotted line on the dash-dot graph, fig 6) shows its maximum for approximately the same period. The comparison of the radio-atmometric graph with the other graphs will be deferred until the graph of average sunshine duration has been considered.

*Radiation in terms of sunshine duration.* The only radiation records available for many parts of the country and for a number of years are those of sunshine duration. Marvin sunshine recorders are operated at many stations of the United States Weather Bureau, and their records have been published. It is unfortunate that these have been allowed to appear as *percentages* of the possible sunshine duration, rather than as the actual duration values, which might be directly valuable in ecological studies. From these percentages, as they are published, the actual duration values may be derived, however, by the use of tables that give the length of the day-

light period for each day of the year and for different latitudes. Also, the original duration records may be secured from the files of the Weather Bureau offices. McLean has emphasized that these records represent only the duration of sunshine having more than a certain approximately constant total energy value, the intensity necessary to cause the recording mechanism to operate; the instrument does not record variations in radiation intensities either above or below this threshold value. The actual total intensity for any period recorded as sunny may have had any value between this minimum and an unknown maximum, the maximum value depending upon latitude, season, hour, haziness, and possibly such more remote phenomena as the occurrence of sun-spots.

The 4-week summation values of actual sunshine duration, as shown by the Marvin recorder at the Baltimore Weather Bureau station, are represented graphically in figure 6 (dash-dot line). This graph is very irregular, especially for the summer, the irregularities being doubtless due to variations in cloudiness. A maximal summer region and a minimal winter one are clearly shown, and the smoothed graph presents the main features when the summer irregularities are neglected. The yearly maximum (279 hrs.) corresponds to the 4-week period ending September 11 and the minimum (122 hrs.) occurs for the 4-week period ending January 29. The maximum value is slightly more than twice as great as the minimum. The maximal region (about 252 hrs. for the 4-week period) of the smoothed graph occurs for about one month (August); it is not represented as occurring until from four to six weeks after the occurrence of the summer solstice. The minimum duration value (about 126 hrs.) occurs for the periods ending January 15 and 29, considerably later than the winter solstice. This minimum appears to lag several weeks behind the minimum of the radiation graph as obtained from the radio-atmometric data in the greenhouse.

*The radiation graphs compared to other graphs.* Attention is called to the fact that some of the irregularities of the evaporation and transpiration graphs appear to correspond to similar irregularities in the radiation graphs for the spring and summer. Such correlations might be expected, since the rate of water loss from the white sphere is surely determined, to some extent, by radiation (the white sphere does not reflect nearly all the radiation received), and since the rate of transpirational water loss from plants is well known to be influenced by sunshine variations. There are also several apparent correlations between the radio-atmometric graph and those of increase in dry weight and of transpiration per unit of leaf area, and similar but less pronounced correlations may be observed in the case of the water-requirement graph.

The maximum of the sunshine duration graph occurs for the same time as the maximum for temperature range and it closely approxi-

mates the maxima of radiation and evaporation values of late summer, as is also true of the high transpiration rates of late summer. The time of the minimum duration value corresponds exactly with the minima for transpiration and for leaf-area and dry-weight increase, and it occurs two weeks earlier than the minimum rate of stem elongation. Agreement is also good between this minimum and those of the areal coefficient of dry-weight increase and the areal coefficient of transpiration. Apparently no correspondence is shown with the water requirement graph. The irregularities of the sunshine-duration graph do not appear to be related to any of the other graphs, although correspondence is good in some cases for the transpiration graph.

### *Temperature*

The temperature data here considered are those of daily means and daily ranges, for the 4-week periods. Daily mean temperature is the usual temperature index employed by climatologists. It fails to indicate anything with reference to rates of temperature fluctuation within the day, and, since the rate of change of temperature may be very important in the determination of plant growth rates<sup>14</sup>, the data of daily range are here introduced as indices of comparative rates of daily temperature fluctuation. Different writers have employed other temperature indices<sup>15</sup> but the daily-mean and daily-range values will alone be brought into the present discussion.

*Average daily mean temperature.* The graph of daily mean temperature (fig. 6) shows its maximum value (31°C.) as occurring for the 4-week period ending August 28. There are two secondary maxima with much lower magnitudes occurring for the periods ending May 8 and November 20. It is interesting to note that these secondary maxima represent about the periods within which artificial heat was discontinued (April 21) and begun (October 19). The lowest average daily mean (20° C.) occurred for the four periods ending January 15 to February 26.

The graph of daily mean temperature shows a pronounced agreement with that of evaporation; the two curves have the same general shape and their main irregularities agree as to the period to which they correspond. The graph of transpiration exhibits some marked agreements with that of daily mean temperature, but none of the other plant graphs shows even a remote correspondence to this temperature graph.

*Average daily temperature range.* The 4-week averages of the daily temperature ranges form a graph that is quite different from

14MacDougal, D. T. The auxothermal integration of climatic complexes. Amer. Jour. Bot. 1: 186-193. 1914.

15—Among these are the different types of remainder indices, the exponential indices based on the van't Hoff principle and the Livingston physiological indices. For a general discussion of these and their relations see: Livingston, B. E. Physiological temperature indices for the study of plant growth in relation to climatic conditions. Physiol. Res. 1: 399-420. 1916.

that of average daily means. The maximum value ( $16^{\circ}$  C.) occurs for the period ending September 11. The temperature range is comparatively high for that portion of the year including the periods ending from June 5 to October 23. The minimum ( $9^{\circ}$  C.) occurs for the period ending December 4. After this period the values gradually become greater, but a rapid increase toward summer values begins with the period ending April 24. A much more uniform set of temperature conditions prevailed during the period when the greenhouse was artificially heated than are shown for the remainder of the year. The two radiation graphs show several similarities, in direction of curvature, to this graph of daily temperature range; when the daily range was greatest the total radiation was apparently high, probably because increased intensity of sunshine raised the day temperatures for a time and thus increased the daily range. Both temperature graphs slope upward through the summer period and the general form of the transpiration graph does the same, but the graphs of weight and areal increase both show a general downward slope for the summer period.

#### *Instrumental Data for the Sheltered Series*

Graphs of the instrumental data obtained from the instruments within the cheese-cloth shelter are represented as dash lines in figure 6. Within the shelter the evaporating power of the air was considerably lower than in the unshaded greenhouse. This difference was relatively more pronounced during the winter period of high evaporation rates. These lower atmometric values may be related to the increased air humidity, the decreased air circulation and the decreased amount of radiation received within the shelter. The radio-atmometric graph of the sheltered series shows a flatter curve for the maximal period than does the corresponding graph for the greenhouse outside the shelter. Reference to the two temperature graphs of the sheltered series (dash lines, fig. 6) shows a close agreement between each of these and the corresponding one of the exposed series but the graphs for the exposed series, show slightly higher values in nearly every case. This small difference is relatively greater in winter than in summer; that is, the percentage effect of the shelter in lowering the temperature values is greater when the values themselves are lower.

#### *General Conclusion from the Instrumental Data*

The graphs shown in figure 6 bring out the varying conditions of a greenhouse for a single year, as these conditions affected the recording instruments. The component of this climatic complex whose intensity varied most was that of radiation in the unshaded greenhouse, as measured by the radio-atmometer. For approximately two-thirds of the year (period ending March 13 to period ending November 20)



this measure of radiation was fairly constant within the shelter. Thus total radiation (as here measured) may be kept approximately the same in a greenhouse throughout the year by introducing the proper kind of shade for the period just mentioned. This is more or less thoroughly accomplished by the common practice of applying a cloth shade or paint or white-wash in the spring and removing it in the fall. Of course the dates of application and of removal should be different for different places, and the shade might be gradually increased throughout the spring and decreased during the fall.

The moisture conditions met with in this study varied most markedly during the summer period. Within certain limits these variations might have been decreased, no doubt, by drying or wetting the floor and walls of the greenhouse, etc. For example if the greenhouse has been kept in a more humid condition during the four weeks preceding May 8 the point plotted for this date would surely have been lowered, thus making a smoother graph. Likewise the low summer value might have been raised by drying out the greenhouse. Moisture conditions may thus be varied in ordinary greenhouses by manipulating temperature and humidity controls. A quick reading atmometer<sup>16</sup> may be used for determining the moisture conditions of a greenhouse, or other room, in as short a period as a minute.

The effects of artificial heat on the temperature conditions have already been noted and an approximate control of these conditions is quite familiar to growers of greenhouse plants. The temperature curves in figure 6 show that the cheese-cloth shade made practically no difference in the air temperature. Of course both sheltered and exposed temperature data refer to air temperature and not to the temperature of objects exposed to solar radiation.

#### GROWTH IN HEIGHT AS RELATED TO TEMPERATURE.

McLean found in his work with soy-bean, which was somewhat similar to the present study, that seasonal marches were clearly in evidence for several plant criteria and that the rate of stem elongation showed general correlations to temperature conditions. On this account, a somewhat more detailed study of the rates of stem elongation and the temperature conditions of the present study, is here introduced.

The weekly stem-height values for the exposed series, as given in table IV, are plotted as ordinates in figure 7. As is true in the other graphs, these values are plotted at the ends of their respective time periods (week periods in this case). The average heights of the seedlings when the different sets were started are also plotted. The growth curve of each set of cultures is represented by a full line; these height values are to be referred to the right hand column (H) of the double scale. The broken lines represent the season-

<sup>16</sup>—Johnston, Earl S. and Livingston, Burton E. Measurement of evaporation rates for short time intervals. *Plant World* **19**: 136-140. 1916.

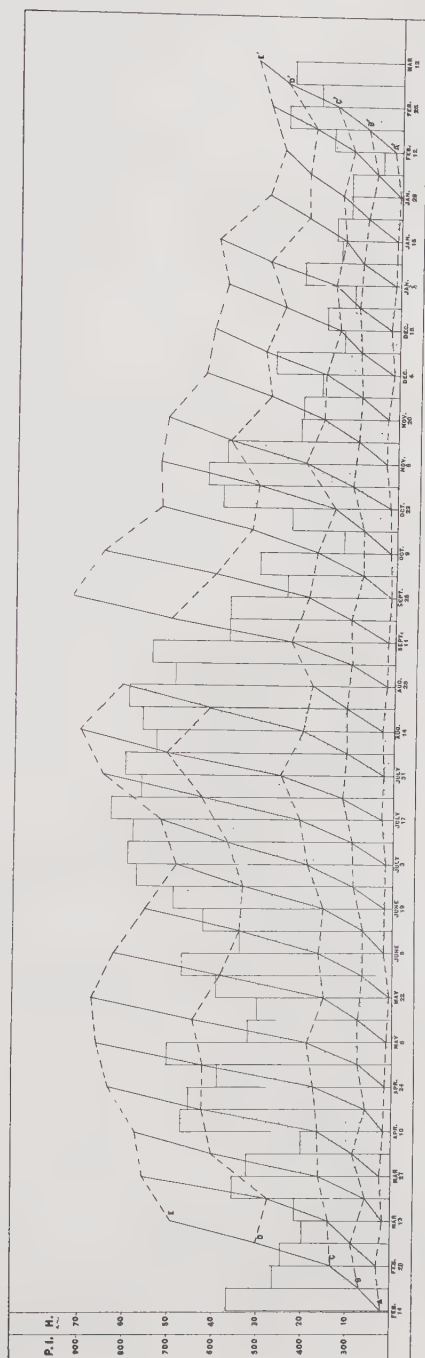


FIG. 7.—Graphs of height and physiological indices plotted from the actual average weekly height data and weekly physiological index values respectively. Height graphs of the average individual culture sets are indicated by full lines and the seasonal march of the height values at the beginning, middle and end of the four-week period and at the end of the first, second, third and fourth weeks are indicated by the dash lines AA, BB, CC, DD, EE and FJ respectively. Weekly physiological indices are plotted as blocks.

al marches of these height values at the end of the first, second, third and fourth week of growth (BB', CC', DD', EE', respectively) and at the beginning of each 4-week period (AA').

In addition to these height measurements, figure 7 shows a series of shaded blocks representing the values of the physiological-summation index of temperature efficiency for elongation of young maize plants (see table IX). The height of each block represents the magnitude of this summation for its particular week; these heights are to be referred to the left hand column (P. I.) of the double scale.

A general inspection of the seasonal growth curves shows that the three upper curves are markedly similar in form. It appears that the fourth week curve (EE') is only slightly different from the second week curve (CC'), only it is placed higher on the chart. The set beginning April 24 gives the maximum for the curves CC' and EE', and the one beginning June 5 gives the minimum for each of these curves. Another maximum is shown for each of these curves by the set beginning July 17, and still other maxima are shown by sets beginning August 28, December 18 and February 12. This agreement between the 2-week and 4-week curves is not good at every point, but the 2-week exposure period for these buckwheat plants seems to be generally just as useful as the 3-week or 4-week periods, when stem height is used as the criterion of growth-rate. In this respect the results of this study are in agreement with those obtained by McLean with soy-bean.

There is a marked difference in shape between the growth curves for the first and second 2-week periods of individual sets. The section of the curve representing the second of these periods is practically a straight line in nearly every case, while the section for the first two weeks of growth is nearly always concave upward. This means that for the second two weeks the increasing height generally varied as a simple linear function of the time term. In other words, the environmental conditions did not generally fluctuate sufficiently to prevent the internal conditions present at the beginning of the second 2-week period from apparently determining the rate of elongation that was practically maintained throughout the second 2-week period. Of course, there are exceptions to this rule, but it holds in most cases. It may be that the exceptions are related to unusually great temperature changes. The rule just considered appears to mean that, with the fluctuations in environmental conditions encountered in these studies, the rate of stem elongation for the third and fourth weeks was *predetermined* by the conditions that were effective during the first two weeks. These earlier conditions appear to have determined the physiological nature of the plant at the end of the second week, and this in turn seems to have determined the slope of the line representing the time-height graph

for the following two weeks. During the second 2-week period the plants were generally not susceptible to influences that might have been exerted by the climatic fluctuations of the second period. It therefore appears that these buckwheat plants were much more sensitive as climatic instruments during the first two weeks than during the second. But it must be remembered that this conclusion applies only for the kinds and degrees of climatic fluctuations met with in this work and only for the single growth criterion of stem elongation.

The maximum in the 2-week curve (CC') occurs for the same 2-week period as that for which the physiological summations reaches its greatest value. There is a corresponding maximum in the 4-week curve, but this is not so great as the maximum for the period ending September 25. The depression in the 4-week curve for the period ending July 3 corresponds to the depression in the 2-week curve for the period ending June 19. The physiological summation value for the first two weeks of this set is less than that for the first two weeks of the set immediately preceding and of the one immediately following.

With this principle in mind, attention may be turned again to the exceptionally low elongation rates shown for periods about the summer solstice. The retarding effect of increased radiation of some kind, on the rate of stem elongation, may of course overcome the accelerating effect of increased temperatures. The shorter wave-lengths of the visible spectrum (blue and violet light) are known to retard the rate of stem elongation in such plants as buckwheat. Since radiation of these wave-lengths supplies much less energy than that of longer wave-lengths (red to green light), it is possible that the shorter waves may have had an unusually high intensity for the periods about the summer solstice, without producing any noticeable effect upon the total income of energy for the period, as this income was measured. The fact that the radio-atmometric data (table X and fig. 6) fail to show exceptionally high values for the exposed periods about the summer solstice does not therefore oppose the idea that these periods were characterized by unusually high intensities of the waves that act to retard stem elongation. If it be supposed that radiation of shorter wave-lengths was maximally effective in retarding the rate of stem elongation during the periods closely preceding and following the summer solstice, and that this effectiveness of that kind of radiation was not recorded by the radio-atmometer, then the low height values shown about the solstice may be regarded as a special radiation effect. On astronomical grounds it would be expected that the total radiation values should reach their maximum with the summer solstice (the radio-atmometer shows this maximum as occurring at a later date), but it must be remembered that this study refers to conditions in a greenhouse, where special influences may have been active. This hypothesis is strengthened by an examination of the region about the summer solstice in the height graph of the sheltered series (fig. 4), which brings out the



fact that the rate stem elongation was not retarded as much in the sheltered plants as in those more directly exposed to the influence of radiation of shorter wave-lengths. The cheese-cloth shade cut out still more of this radiation in addition to what was already cut out by the glass roof and walls of the greenhouse. The data for the sheltered series suggest a slight general depression in the rate of stem elongation for the whole summer (June, July and August), but it is perhaps safe to suppose that a normal graph would be nearly horizontal for this summer that a normal graph for the exposed series may be supposed to have a marked depression about the time of the summer solstice.

If it be considered as true that, with the kinds and degrees of climatic fluctuation dealt with in this study, the rate of stem elongation for the second 2-week period was generally predetermined by the climatic conditions of the first two weeks, it becomes especially interesting to apply this generalization to the problem concerning the exceptionally low rates shown for periods about the summer solstice. According to this generalization the differences in the final heights recorded at the ends of the 4-week periods had been determined by climatic conditions that were effective during the first 2-week period in each case. Thus, the climatic graphs for the first 2-week period of each 4-week period should be studied if we seek to interpret the final height values by means of instrumental data; the climatic fluctuations for the second 2-week period in each case may be neglected as not effective. This suggestion will not be followed out in the present paper, but it may be employed for a tentative interpretation of the peculiar solstice concavity in the height graph. No first 2-week period centers on the date of occurrence of the summer solstice, but the 2-week periods beginning June 3 and June 19 lie practically one on either side of June 21. These two initial 2-week periods gave low rates of elongation, but they are not peculiar in this; however, the plants that had the experience of these two initial 2-week periods afterwards showed exceptionally low elongation rates for the second 2-week period. What ever happened climatically during these two initial periods it seems to have been predetermined that the final 4-week heights of these plants should be low (4-week values plotted for July 3 and 17). It may be that the environmental conditions that are effective during very young stages of a plant's development from the seed exert a markedly lasting influence on its later development, so much so that these conditions of the juvenile period may frequently be dominant in determining the final height of the plant. This tentative suggestion seems to be worthy of further attention at the hands of physiologists; it may be construed as possibly placing more emphasis on the seedling environment of agricultural plants than is now customary among experimenters in this field.

Turning finally to the physiological temperature summations, these do not seem to correspond with the rates of stem elongation in more

than a broad and general way. Of course it is to be remembered that the physiological indices here used are based on the growth of young maize seedlings and are not to be expected to represent corresponding indices for buckwheat as grown in this study, but it is also to be borne in mind that many climatic conditions besides temperature were surely influential in these tests, and that the observed growth rates are integrations of the several influences to which the plants were exposed. It is not to be expected that any single climatic condition can be so expressed as to give calculated growth rates that agree with the actual ones, unless all other conditions are effectively alike for all cultures considered.

An indirect line of evidence indicating a correlation between stem elongation and temperature conditions lies in the fact that the graphs representing the measurements taken inside the cheese-cloth shelter are almost identical with the corresponding ones representing those taken outside. There are, however, some differences for the summer months, when radiation intensity was near its maximum. No other equally striking similarity between plant and instrumental data has thus far been found in the present study. If temperature be regarded as the primary climatic condition influencing the rate of stem elongation, then radiation, should be considered as an important secondary one, especially in cases where the total radiation intensity becomes great enough to retard the rate of this plant process. Whether or not these same relations may be found to hold for other plants or for buckwheat plants with different chemical environments, etc., must be left undetermined for the present.

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## VITA

The writer was born at Quarryville, Lancaster County, Pennsylvania, February 5, 1889. He attended the High School and State Normal School, East Stroudsburg, Pennsylvania, and after being graduated from the latter institution in 1909 he entered Dickinson College, from which he received the Ph. B. degree in 1913 and the A. M. degree the following year for work done in botany. He was instructor in science in the Pennington School for Boys, Pennington, New Jersey, for the year 1913-1914. During the summer of 1914 he assisted in work for the Maryland State Weather Service, on a study of climate and of plant growth in Maryland. During the years 1914-1917 he attended the Johns Hopkins University as a graduate student in plant physiology, chemistry and physics. He was appointed University Scholar in plant Physiology for the year 1914-1915 and was reappointed for the years 1915-1917. He was research and laboratory assistant to Professor B. E. Livingston, of the Laboratory of Plant Physiology, for three years, and during the summer of 1915 was engaged in research under Professor Livingston's direction at the Desert Laboratory of the Carnegie Institution of Washington, at Tucson, Arizona.

